SLAVE RIVER DELTA

INTERPRETATIVE EXPLANATION

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1. INTRODUCTION

1.1 Terms of Reference

The terms of reference of the Slave Delta interpretation project covered in this report are set out in a letter dated September 11, 1980, from Jack T. Cole, P.Eng., Science Procurement Manager, Science Centre, Department of Supply and Service, Ottawa, as follows:

"1. Analyse and interpret the available aerial photographs and hydrologic and sediment data to determine the historic development of the Delta, the Delta's present rate of change (growing, shrinking or stable), and the stability of distributary channels and status of the water in the Delta (increasing, decreasing, or stable).

"2. Analyse and describe the processes controlling change in the Delta (spring flood, ice jams, sediment load, characteristics of Great Slave Lake) and what factors are maintaining the Delta in a disclimax stage (high productivity).

"3. Submit a final report on the results of the above work. The report will provide a detailed narrative explanation of findings supported by appropriate maps. The report will contain an executive summary at the beginning and conclude with a synthesis which will describe the interrelationships between the various parts of the study."

1.2 Components of the Study

In order to understand the postglacial development of the Slave Delta, and changes in the Delta, it is necessary to interpret the

depositional environment and history of the entire Slave River Lowland, including the modern Delta composed of active and inactive parts. Accordingly, a major component of the present study entailed the mapping of depositional environments and of the different types of sediment within the Slave River Lowland. Emphasis has been placed on the history of postglacial alluvial and deltaic sedimentation and erosion, and changes in the active delta related to stability of its main distributary channels.

In addition to an explanation of the postglacial geomorphic history of the Slave River Lowland, including the Slave Delta at its northern extremity, data on Slave River hydrology and sedimentation have been analyzed and interpreted.

1.3 Geological Setting

Physiographically, the Slave River Lowland lies on the eastern side of the Great Slave Plain Division of the Interior Plains Region (Figure 1). The Slave Delta is located at the terminus of the Slave River, where it discharges into Great Slave Lake. The modern Slave Delta is situated at the downstream end of the Slave River Lowland, which is a long and narrow alluvial-lacustrine plain that extends from the Little Buffalo River on the west to the Talston River on the east.

The Slave River Lowland is underlain by Middle Devonian rocks (map unit 9 in Figure 2). The sedimentary rocks consist mainly of

gypsum, salt, limestone, and breccia in their basal strata, and of dolomite and limestone in their upper strata. Scattered bedrock hills appear in the Lowland, and these consist of carbonate rock at or very near the surface. To the east, Archean rocks of the Shield Region (Figure 1) are mainly granitic and granitic gneiss rocks (map unit 4, Figure 2).

Surficial deposits consist mostly of fine sand and finer-grained sediments of alluvial, deltaic, and lacustrine origin. They are generally thin and overlie late glacial and early postglacial deposits carried into glacial Lake McConnell (Figure 3).

1.4 Climatic Setting

Data on daily mean, maximum, and minimum temperatures, total precipitation and rainfall are given for Fort Smith, Fort Resolution and Hay River recording stations in Table 1 for the period 1931 to 1960. An exception is the daily mean temperature for Fort Resolution, which is given for the 22-year period from 1931 to 1960.

Total annual precipitation is low at all stations. Annual snowfall is about 47.5 inches. Fort Smith has a shorter and cooler frost-free season than Fort Resolution, but a longer and warmer growing season. The long frost-free season at Fort Resolution and Hay River is due to the influence of Great Slave Lake in autumn.

2. SOURCES OF DATA

2.1 Aerial Photography

Nine sets of aerial photographs were obtained from the National Air Photo Library in Ottawa. They cover all or parts of the modern delta of the Slave River and the lower part of the Slave River Lowland above the modern delta. Some of the sets of airphotos cover more than 4000 km^2. All of the photography is black and white panchromatic except one set of normal colour photographs that were taken in August 1966.

Following are the date and scales of the airphotos:

Date	Scale
August 1930	1:12,000
July 1946	1:25,000
August 1954	1:70,000
September 1957	1:25,000
July 1960	1:40,000
August 1966	1:24,000
September 1970	1:60,000
August 1972	1:8,000
July 1973	1:25,000
July 1979	1:20,000

2.2 Satellite Imagery

The following Landsat imagery was obtained and examined:

Date	Image number	Type of image	Band(s)
Oct 20/73	E 1436-18145	Colour composite 8	4,5,7
Aug 18/75	E 11121-17562	Colour composite 8	4,5,7
July 31/80	E 22017-18094	Colour composite 8	4,5,7
July 31/80	E 22017-18094	Colour composite 9	5,6,7
Sept 20/72	E 1059-18215	B & W print	5

In order to show suspended sediment concentrations off the mouth of the Slave River, and along the Great Slave Lake shore to the east and west, 35-mm slides were made of two colour composite Landsat images: August 1975, and July 1980. A density sliced image was also produced from Landsat band 5 image acquired on August 18, 1975. A digitally (computer) processed image was prepared from colour composite 9 (image acquired July 31, 1980). This latter image shows suspended sediment in the Slave River and adjoining Great Slave Lake. A second digitally processed false colour image was produced from colour composite 9 (acquired July 31,1980) to show vegetation in the lower Slave River Lowland and the nearby Precambrian Shield to east. Altogether five 35-mm slides were made and all were delivered to Mr. Gordon Lewis, Environment Canada, on January 30, 1981.

2.3 Other Main Sources of Data

Other main sources of data relate to the following soils, geological, hydrologic,and sedimentation maps or reports:

Craig, B. G.

1965 Glacial Lake McConnell and the Surficial Geology of Parts of Slave River and Redstone Map-Areas, District of Mackenzie. Geol. Sur. Can. Bull. 122.

Davies, K.F.

1981 Slave River Delta Hydrology Study. Prepared for Mackenzie River Basin Task Force, Inland Waters Directorate, Western and Northern Region, Environment Canada, February.

Day, J. H.

1972 Soils of The Slave River Lowland in the Northwest Territories. Soil Research Institute, Central Experimental Farm, Canada Department of Agriculture, Ottawa.

Environment Canada

1975 Waves Recorded Off Hay River, N.W.T., June 18, 1975 to September 30, 1975. Data compiled by Marine Envir. Data Service, Ottawa.

Environment Canada

1980 Slave River Delta Hydrology Study. Interim Report from Water Survey of Canada, Calgary to Mackenzie Basin Task Force.

Hydrological Atlas of Canada

1978 Published by Government of Canada, Ottawa.

Noble, P., and Comfort, G.

1980 Pipeline damage by ice ridges. Paper submitted to the NRC Workshop on Ice Ridging, Calgary.

Northwest Hydraulic Consultants Ltd.

1980 Slave River Hydro Feasibility Study. Sponsored by the Alberta Environment, Edmonton.

3. GENERAL DISCUSSION OF DELTA CHARACTERISTICS

This section deals with the general framework of deltas, and includes a discussion of characteristic delta types, processes, and sediments. The information presented is a digest of material extracted from several papers and books containing data on delta formation and behaviour. A literature review was made before the detailed examination of the Landsat imagery and the stereoscopic study of the black and white panchromatic photography. However, most of the data contained in this section,and the illustrations used,were extracted after completion of map and airphoto interpretation, so that the information would be relevant to the Slave Delta setting.

3.1 Delta Types

There are three basic types of deltas (Figure 4), and examples of all three are found in the Mackenzie River basin (Figure 5). They are referred to as a) arcuate, of which the Slave Delta is a stunted variety, i.e. a delta along which part or all of the shoreline has been or is being modified by waves and longshore currents; b) birdsfoot, or digitate, of which the Peace and Athabasca Deltas are classic representatives; and c) estuarine, of which the Mackenzie Delta is the best example in Canada.

The eastern, older portion of the Slave Delta (Figure 6) is a stunted arcuate type; here the Delta has been blunted and smoothed by wave action and longshore currents. The active western part is characteristic of a little-modified arcuate delta. In this area the Slave Delta contains 11 principal distributary channels, indicated in Figure 7.

3.2 Delta Processes

The processes that accompany delta formation are visualized best by means of annotated diagrams. A good example is Figure 8. As seen in this figure, delta sediments build outward into a lake or into the sea on both sides of a distributary channel. The flow from distributaries resembles the expansion of submerged jets. Shoals built at the mouth of distributaries commonly advance as indicated in Figures 8, 9, and 10. The three diagrams on the left in Figure 8 represent the present situation at the mouth of Sawmill Channel in Nagle Bay (Figures 6, 7), where a subdelta has formed.

The processes shown in the middle and right diagrams of Figure 8 are well illustrated on the airphotos taken September 26, 1970 -- particularly at and between the mouths of Old Steamboat Channel and Resdelta Channel.

The geometry of deltas built into lakes is determined by interaction between fluvial and lacustrine processes. The active delta may be divided into two parts: an intradelta part, and a prodelta part. The

intradelta part consists of a complex of distributary channels, natural levees bordering these channels, crevasse splays, and interdistributary basins consisting of swamps, marshes, bays, lagoons, and sloughs. In most modern deltas the proportions of the subaerial intradelta area occupied by distributary channels, levees and splays, and interdistributary floodbasins are roughly 5%, 25%, and 70% respectively. Distributary channels are characteristically serpentine. These channels occur widely over both the active and inactive parts of the subaerial deltaic plain.

Shoreline configuration is determined largely by the relative importance of river deposition,on the one hand,and wave and current erosion on the other. A break in offshore delta slope often occurs at depths equal to the effective depth of wave erosion, commonly about 10 m in the ocean and large deep lakes and much less in sheltered bays. In shoal lakes a break in slope usually occurs at quite shallow depths. This break in slope marks the delta front.

The counterpart of subaerial delta deposition is subaqueous deposition, which results in the formation of topset beds, foreset beds (extending outward and dipping downward in inclined, parallel strata), and bottomset beds, extending beyond the delta front and consisting largely of soft prodelta clays. Topset beds are usually coarser than foreset beds, and bottomset sediments are finest of all.

Rate of delta front advance depends on several variables. The effects of these variables on slow versus fast growth are given qualitatively in Table 2, and a further description of how these factors operate is given in Table 3. The correlations suggested in Table 2 are helpful to the

photointerpreter assessing changes in the delta front stability since the variables mentioned are often expressed on aerial photographs -- especially comparative airphotos taken at intervals over a period of several decades.

The rate of delta growth is slow (the shoreline may even erode and recede) in high wave and current energy environments, especially if lake levels happen to rise sharply for any reason. Shore erosion is usually caused by intense storms that are generally only a few days in duration. Storms move water onshore and increase the local lake level, a phenomenon referred to as wave set-up (or wind tide).

The appearance of barrier bars, clearly seen in the 1970 airphotos of the Slave Delta, can also be an important factor influencing rates of shore erosion locally.

Rate of delta advance is slower where the offshore gradient is high,or where the inflowing sediment happens to be filling a large, deep nearshore basin. It can also be slow in places where the lake bottom is actively subsiding through the compaction of soft underconsolidated clays (Figures 10 and 11), or through crustal downwarping. In addition, low rates of sediment influx, small content of sand in the inflowing sediment, and low rates of vegetation growth are all associated with slow delta front advance. A rapidly advancing shoreline on the other hand may be expected in places where there is a large supply of sandy sediment, and in places of active land emergence, as in regions of rapid postglacial isostatic rebound. Parts of a delta that have been cut off from active river sedimentation or that are experiencing rapid crustal subsidence may erode and retreat.

3.3 Delta and Fluvial Sediments and Forms

There is continuous transport and redeposition of particles in turbulent moving water. The finer particles of sand, silt, and clay are transported in suspension, with coarser sand and larger particles carried along stream bottoms. Where the current velocity decreases the transport capacity also decreases, and some of the sediment load is deposited. At river mouths, where a stream enters a large body of still water, usually there is a rapid decrease in current velocity. Where the suspended sediment is nearly all silt and clay it often spreads over a large area of the lake before being deposited. This is evident in Landsat images of the Slave River delta (see the five 35 mm slides that accompanied the letter to Gordon Lewis dated January 30, 1980).

With initial deposition of bed load material, a bar develops in front of the river mouth (Figures 8, 9 and 10). With continued deposition, an island is formed separating two river distributaries.

Stream patterns in deltaic environments are greatly affected by lacustrine and marine processes, and can differ from patterns formed on broad floodplains, such as occurs between the active Slave Delta and Fort Smith. Schematic diagrams illustrating the types of landforms and deposits occurring on the floodplain north of Fort Smith are shown in Figures 12, 13, 14, 15, and 16. Figure 17 is a map of the landforms and deposits of the Slave River Lowland, extending from Fort Smith at the Alberta/Northwest Territories border to Great Slave Lake. Figure 18 is a larger scale map of the landforms and deposits of the active and inactive Slave Delta and of the downstream portion of the Slave River Lowland.

With the deposition of sediments at the delta front the length of distributary channels increases, resulting in a reduction of slope and transport capacity. Long continued delta aggradation results in partial filling of the channels and in overbank spill, which creates secondary channels. Overbank flooding and deposition are the processes by which the natural levees of a delta develop. In time the levees seal off flow from the parent stream. In this environment, abandoned distributaries, often containing elongate sloughs, are numerous. Where channels are abruptly sealed, further bed load addition is limited and channels may change very little for decades, creating habitat for wildlife and waterfowl.

Continually shifting distributary courses lead to the building of successive subdeltas. A good example is Sawmill Delta in Nagle Bay. As Sawmill Delta protrudes farther and farther into Great Slave Lake, its slope and capacity decrease, and shorter routes are found in nearby bays, marshes and swamps. A new distributary course is initiated, and a new subdelta or crevasse splay begins to form (see Figure 8, lower left diagram).

Processes, environments, and deposits characteristic of active deltas are widespread on the alluvial plain above the present Slave Delta on the Slave River Lowland (Figure 18). Floodbasins (backswamps), natural levees, crevasse splays, and abandoned channels on alluvial floodplains (Figure 17 and Table 4) all have their counterpart in interdistributary bays and marshes, levees, subdeltas, and abandoned distributary channels on deltas (Figure 18); their interpretation helps in understanding how the landscape was formed and how it may be used.

The grain-size distribution and organic content of deposits on floodplains developed on very low gradient rivers like the Slave River are often similar to sediments found in corresponding subenvironments on actively forming large deltas (compare Figures 15 and 16 for rivers and Table 5 for deltas).

In the case of large modern deltas, topset beds are usually absent and foreset slopes are usually poorly developed, if at all. In this report the term "delta front slope" is used for steeper parts of the bottomset slope, and the term "prodelta slope" is used for the lower and gentler parts of bottomset slopes.

4. GEOMORPHIC PROCESSES AND EVOLUTION OF THE SLAVE RIVER LOWLAND AND SLAVE DELTA

Regional controls affecting the evolution of the Slave River Lowland and Slave Delta are shown in Figure 1 (physiography), Figure 2 (bedrock geology), and Figure 3 (glacial Lake McConnell). Unfortunately, the information contained in these three figures is not detailed enough to permit a proper understanding of significant past depositional environments, which is required to reconstruct the early postglacial and later geomorphic events and to evaluate their significance in the evolution of the lower Slave River floodplain and the Slave Delta. It was therefore found necessary to prepare a map of the geomorphology of the Slave River Lowland north of the Alberta-Northwest Territories border (Figure 17), in which significant depositional environments are emphasized. Figure 18 shows in greater detail the depositional environments, landforms, and surface materials of the Slave Delta and lower Slave River floodplain. This figure also shows internal drainage, permafrost, and vegetation. The detailed legends accompanying Figures 17 and 18 are intended to be self-explanatory.

The following sequence of processes and events has been reconstructed from the interpretation of data shown on Figures 17 and 18 (see also the 1:200,000 scale map of Figure 17a, which is contained in the map pocket):

1) The Slave River formed two extensive belts of lateral accretion topography downstream of Fort Smith. The two major belts are located (i) between the north end of the Fort Smith sand delta and about latitude 60°45', and (ii) north of latitude 61°00'.

2) During the draining and lowering of glacial Lake McConnell and the shifting of its shoreline from Fort Smith (latitude 60°, elev. 183 m) northward to latitude 61°, very little development of raised beaches took place, and no major shoreline erosion events are recorded. North of latitude 61°, however, the occurrence of raised beaches become much more common (Figure 17), suggesting episodes of past shore erosion.

3) Belts of multiple beach ridges appear to have developed alternately, first on the east side of the Slave River, and then, some distance downstream, on the west side of the Slave River (see Figure 17). This is a remarkable evolutionary characteristic of the lower Slave River Lowland and modern Slave Delta. West (or east) of each belt of raised sandy beaches, a contemporaneous delta appears to have formed, similar to what is occurring at present between Fort Resolution and the mouth of the Talston River. Two major sequences of beach ridges can be observed east of the Slave River as well as a shore that is presently undergoing wave and current modification. On the west side of the Slave River there are two raised (relict) beach ridge sequences. Abandoned and moribund distributaries on relict deltas appear above each belt of raised sand beaches, and distributaries are truncated by the beach ridges. These events indicate clearly that the delta advance on both sides of the Slave River has been and still is marked by intervals of sedimentation and delta advance followed by wave and current erosion and shoreline retrogression.

4) Spits have formed along a wave-dominated, retrograding coast from Gaudet Bay to Resdelta Channel (Figure 17), while active delta deposition and a prograding coast has formed from Resdelta Channel to Nagle Bay (Figures 26 to 37). However, as the shoreline changes indicated by Figures 26 to 33 disclose, the prograding process in the active delta area has been rather jerky.

5) Large interdistributary open bays form and eventually become closed basins. In time these fill with mineral and organic material and become marshy or swampy.

6) The dominant wind direction forming the sequences of raised beaches north of latitude 61° appears to have been from the west and northwest (note the long westerly and northwesterly fetches associated with the shape of Great Slave Lake).

7) After formation of a belt of beach ridges, a serpentine distributary channel follows a course along the coast and separates the beach ridges from later (younger) deltas constructed lakeward.

8) During the jerky course of delta progradation, small islands of carbonate rock and till represent sources of coarser sediment for the creation of surrounding wave-modified platforms (unit 6, Figure 17b), beach ridges (unit 5), and spits (unit 10). Nearshore shoals appear to be ephermal: grow, then erode and disappear.

9) Where the water in Great Slave Lake is shallow and warm, and is fed by nutrient-rich sediments discharged by the Slave River, emergent (and possibly submergent) vegetation grows -- usually around and between small subdeltas; the latter are then partially protected from storm wave action and from damage by moving ice in spring break-up.

5. ENVIRONMENTAL FACTORS MODIFYING THE SLAVE DELTA OTHER THAN HYDROLOGY AND SEDIMENTATION

Several factors may affect the changes in delta shorelines and distributary channels that are observable in airphotos taken over the last half century. These include subsidence, density currents, permafrost and vegetation, quantity and size of sediments carried to the Delta, and waves, currents, and ice on Great Slave Lake. Hydrologic and sediment factors are discussed in greater detail in Section 6 of this report.

5.1 Compaction Subsidence

There are two major phases in the cycle of a delta. In the constructional phase the river extends lakeward (or seaward); in the destructional (erosional) phase the lake or sea encroaches upon newly formed delta land. Both phases have distinct identifying characteristics, and both are evident along the shore of Great Slave Lake between Fort Resolution on the west and the mouth of the Talston River on the east (Figure 17). Shoreline erosion east of the Resdelta Channel is believed to be caused in part by compaction subsidence, since the deposits in the Slave Delta are loose and fine grained (see also Figure 11).

Following abandonment of the delta distributary system east of Resdelta Channel, active sedimentation appears to have essentially ceased while subsidence continued. The effects are most pronounced in the large interdistributary basins that form lagoons or contain marshes and ponds between Resdelta Channel and the Talston River. Because levees are

heavier than adjacent marshes, they subside more rapidly; and with continuing subsidence and wave and current erosion, the marshes and swamps tend to enlarge and coalesce (Figure 18). In a few years some of the marshy interdistributary basins may become open bays or small lakes. This change from marsh land to open water in shoreline bays appears to have been accompanied by diversion of the Slave River to the west, where the active delta is located.

The process of subsidence from compaction should be distinguished from tectonic downwarping or isostatic rebound following deglaciation. Figure 19 suggests that glacier ice retreated from the Slave River Lowland about 10,000 years ago. The role played by isostatic rebound in Slave Delta modification is unclear. However, it is no doubt partly responsible for the low gradient of the Slave River.

5.2 Density Currents

At river mouths the density difference between inflowing river water and adjoining basin water is caused by differences in suspended sediment and temperature, and by salinity in the case of deltas built into the sea. If the density difference is large, the spread of the inflowing stream is restricted and this in turn influences the rate of sediment deposition and the morphology of the delta front. Contrasts in the density of inflowing river water and that in the receiving basin may give rise to density currents, which can be very significant. The occurrence of density currents off the Slave Delta is suggested by the appearance of the sediment plume so clearly outlined in Landsat imagery, and shown on the five 35-mm slides forwarded to Gordon Lewis on January 30, 1980.

On the basis of the position of the density currents relative to the boundaries of the surrounding fluid, overflow (surface), interflow, and underflow (bottom) currents can be distinguished. Density currents that have a higher content of suspended sediment than the enclosing fluid are called turbidity currents; and they are the most important. Turbidity currents may also be produced by waves, which stir up bottom sediments, and by subaqueous slides forming along delta-front slopes. It is not possible to determine how significant these are without field measurements. Density currents affect the prodelta morphology by forming gullies, reducing the slope on foreset deposits, and forming gently sloping bottomset beds that extend far out into Great Slave Lake.

In interpreting the Landsat imagery, an attempt was made to distinguish three types of inflow situation: (a) where the inflow is denser than the ambient fluid and forms a turbidity current, which inhibits mixing; (b) where the inflow water is similar in density to the receiving water and, given sufficient depth offshore, mixes readily in three dimensions, producing topset, foreset, and bottomset beds; and (c) where the inflow water is less dense and spreads over the surface as a bouyant plane jet. Unfortunately, these three types of inflow could not be confidently distinguished in the absence of field data.

The two colour composite Landsat images, and the two digitally processed images submitted earlier all show the extent of offshore sediment, apparent changes in sediment concentration, and what appear locally to be the effects of density currents. In August 1975, for example, the area of

suspended fine sediment off the Slave Delta extended 35 km out into Great Slave Lake and covered an area of approximately 6000 km^2. In July 1980 the area of suspended sediment was much less -- approximately 2500 km^2.

5.3 Climate and Vegetation

At the Slave Delta the main contributions of climate are the creation of waves and currents from winds, the formation of lake and river ice (agents of destruction), the development of shoreline-stabilizing subarctic vegetation, and the creation of permafrost conditions. All factors are significant at the Slave River Delta.

Vegetation and permafrost conditions change from area to area over and upstream of the active and inactive delta (Figure 18). Both are associated closely with surface drainage conditions. The drier sites tend to be more heavily wooded. Moreover, insulation, shade, and the accumulation of snow in the branches of conifers (mainly spruce) promote permafrost development or its retention once formed. Where it is dry, sphagnum peat promotes the preservation of permafrost in bogs. In the Slave Delta, all wet fens, marshes, and swamps with standing water are believed to contain no permafrost. Characteristic vegetation, and existence and depth to permafrost, can also be correlated closely with landforms and surface materials (see Figure 18).

The effect of microclimate differences on winds, waves, currents and drift ice can be substantial along the shores of the Slave Delta. For example, wave and ice action is expected to be less in Nagle Bay, which is protected to some extent by islands and a spit. As a result, clusters of emergent plants (e.g. scirpus acutus) can be seen in the 1966 normal colour airphotos (Figure 38). Nevertheless, some sets of airphotos show

strong suspended sediment movement patterns within Nagle Bay, possibly formed by incoming waves or longshore currents.

Airphotos and maps of the Slave River Lowland show a lack of wind-blown sand dunes along present and former sand deltas, such as occur on the delta plains where the Liard River and Great Bear River join the Mackenzie River. The reason for the lack of dunes behind the present shoreline and on raised sandy beaches in the Slave River Lowland may be rapidly colonizing vegetation. It may also be the presence of substantial amounts of silt and clay in very fine sand (versus dominantly clean fine sand in the 0.1 to 0.5 mm range).

Vegetation seems to play an important role along the Slave Delta shoreline by stabilizing the soils above the reach of wave action. Organic materials form resistant masses against currents and waves, and the roots of woody scrub brush also stabilize the soil against erosion. Such stabilizing vegetation is assisted by the paucity of 0.1 to 0.5 mm sand particles reaching the coast, as noted above at Nagle Bay, and by offshore islands, spits, submerged bars and shoals that blunt the attack of waves and currents.

Thermokarst development appears to be uncommon in the active delta, as revealed by the nine sets of airphotos extending over a period of a half century, but is extremely common on land above the modern Slave Delta (Figure 18).

6. HYDROLOGY AND SEDIMENTATION

K. F. Davies, in his report on the Slave River Delta hydrology dated February 1981, notes that wildlife within the Delta depends on annual floods carrying nutrient-rich sediments.

Davies also states that ". . . approximately 86% of the flow in the summer months passes through the Resdelta Channel, 5% through the Middle Channel West, and 9% through the remaining 5 channels. During winter periods these percentages change to 93%, 5% and 2% respectively. Flows close to zero were observed in some of the smaller channels during the winter months. Water levels fluctuate up to three metres from low fall conditions to high spring peaks during breakup periods. Two distinctly different spring breakups were observed during the study period. The 1979 breakup was a late breakup with high water levels and subsequent flooding of most of the delta complex. The 1980 breakup was relatively warm and early with low flows and minimal flooding of the delta lowlands.

"Water level fluctuations of 2 to 3 metres, the result of ice jams in the spring freshet, are the predominant cause of flooding of the wetlands within the delta. Water levels from high flood peaks in June, July, and from wind action on Great Slave Lake affect these areas to a lesser extent."

Davies further notes that his study encompassed only two spring breakups and a limited range of flows, and that a much larger range of flows and spring breakups should be monitored.

6.1 Comparison of the Slave, Athabasca, and Mackenzie Deltas

The Athabasca, Slave, and Mackenzie Deltas are three major deltas of the Mackenzie River basin. The Athabasca and Slave Deltas together receive virtually all the sediment load of the Athabasca and Peace River systems, whereas the Mackenzie Delta receives only sediment that originates from the Liard and Mackenzie River systems downstream of Great Slave Lake.

Table 6 gives a comparison of a few statistics for the three deltas. The most notable feature is the small surface area of the Slave Delta in relation to water and sediment inflows, which results from the large depth of water into which it is advancing offshore.

The approximate area quoted for the Slave Delta (Figure 6) includes the active and inactive parts of the modern delta. The active delta area is about 20% of the total area of the modern delta.

6.2 Great Slave Lake: Depths, Levels, Waves, and Ice

Figure 6 is based on Canadian Hydrographic Service Hydrographic Chart 6370, and shows depths of water in feet. Depths reach 30 m only 2 km offshore. The shallow area south of Old Steamboat Channel may reflect past long-continued sedimentation. The main river flow into Great Slave Lake now discharges to the north via Resdelta Channel.

Daily water level data are available for 1934 and for the period 1938-79. Statistics are summarized in Table 7. The period 1968-71 is anomalous due to filling of Williston Reservoir (Bennett Dam) on the Peace River, as shown by Table 8. Monthly levels for the period 1971-79 are plotted in Figure 20.

Wave data are apparently available only for a point in about 20 m water depth off Hay River, where a recording buoy was situated from 18 June to 30 September 1975. Statistics in Table 9 are based on a data report from Environment Canada (1975). Conditions at this location are probably similar to those off the Slave Delta.

Information on lake ice conditions near Hay River was obtained from a paper by Noble and Comfort(1980). Maximum ice thickness is typically 1.2 m in late April. Pressure and shear ridges tend to form 2 to 3 km offshore. Typical ridge dimensions are a spacing width of 30 m, a sail height of 1 to 2 m, and a keel depth of 4 to 8 m. According to the Hydrological Atlas of Canada (1978), freeze-up normally occurs about 1 November and the lake is ice-free about 15 June.

6.3 Slave River Inflows

Figure 21 shows a mean water balance for Great Slave Lake. The Slave River contributes about 85% of the annual outflow from Great Slave Lake. Figure 22 shows a hydrograph of Slave River flows at Fitzgerald, virtually the same as at the head of the Delta. The effect of Bennett Dam on the Peace River can be seen in reduced flow volumes during the filling period 1968-71, and in increased winter flows and reduced summer flows since 1972. Figure 23 shows the mean flow distribution by months for the present regime.

Table 10 lists some flow statistics of the Slave River. The highest flow recorded was in May 1974 during the ice break-up period. Before the completion of Bennett Dam, no annual maxima were recorded before June 11; therefore, it seems possible that the 1974 event was caused by more severe ice conditions and jamming resulting from Peace River regulation.

6.4 Distributary Flows and Delta Water Levels

Limited distributary discharge data for 1978-79 are contained in a preliminary report by Environment Canada (1980) for gauging sites shown in Figure 24. Approximate ranges in flow indicated by these data are listed in Table 11. The most easterly Resdelta Channel carries about 86% of the total flow; the Middle and West Channels carry about 6%, and the rest carry 8%. It appears likely that there has been a dramatic shift in distribution within the historical period, as shown from aerial photographic evidence.

In the 1978-79 observation period, the highest water levels were caused by ice jams in May 1979. These jams resulted in flooding of a large part of the delta. The highest summer levels in 1979 were about 1 m lower. The total range in levels at several of the gauging sites was about 2 m.

6.5 Sediment Inflows

Suspended sediment in the Slave River has been measured at Fitzgerald since 1972, after completion of Bennett Dam. It is likely that the effect of the dam has been fairly small. Nevertheless, some reduction may have occurred in sediment inflows, mainly due to reduction in summer flows. The post-1972 mean annual sediment load is about 30×10^6 tonnes, or in volumetric terms around 20×10^6 m^3 of deposited sediments. Over 50% of the inflow occurs in June/July, with the rest mainly in May, August, September, and October (Table 12).

Bed load in the Slave River is likely to be very small in relation to suspended sediment load.

Typical size distributions in Slave River suspended sediment are 10% sand, 65% silt, and 25% clay.

Typical sediment concentrations in June/July are in the range of 100 to 500 mg/ℓ, with periods of a few days up to several thousand mg/ℓ. A daily maximum of 7600 mg/ℓ was recorded in 1972; the corresponding daily sediment load was 5×10^6 tonnes, 1/6 of the average annual load. Typical daily loads in June/July are in the order of 200,000 tonnes.

The average annual sediment concentration appears to be about 250 mg/ℓ. In terms of western Canadian rivers this is a moderate figure. The relatively high sediment loads of the Peace and Athabasca basins are somewhat diluted by runoff from Canadian Shield drainage into Lake Athabasca. Also, part of the Athabasca sediment is retained in the Athabasca Delta.

If a hydroelectric dam is built at Mountain Rapids on the Alberta-Northwest Territories boundary, all of the sand and most of the silt will be deposited in the reservoir, which will take many centuries to fill with sediment. This could have implications for the stability of the Slave Delta.

6.6 Sediment Balance Versus Delta Changes

On the basis of certain assumptions, a theoretical rate of delta advance can be calculated from known sediment inflow. The following assumptions are made:

1) the average sediment inflow is 20×10^6 m^3/yr;

2) 50% of the sediment inflow is deposited in the delta, and the rest is dispersed in Great Slave Lake;

3) the water depth at the delta front is 30 m.

The corresponding rate of areal advance can thus be estimated as:

$$\frac{0.5 \times 20 \times 10^6}{30} = 0.33 \times 10^6 \ m^2/yr$$

$$= 0.33 \ km^2/yr$$

The total advance in the period 1930 - 1973, as indicated by the aerial photographs, is about 1.5 km over a 20-km long front. The average areal rate is accordingly:

$$\frac{1.5 \times 20}{43} = 0.7 \text{ km}^2/\text{yr}$$

This comparison seems to indicate that the proportion of sediment dispersed in Great Slave Lake may be quite small.

6.7 Regime Characteristics of the Lower Slave River

Table 13 lists some prominent features of the Lower Peace and Slave Rivers. The river distance from the start of the Slave River, at the junction of the Peace River and Rivière des Rochers, to the head of the Delta is about 430 km. The river distance from the lower end of the rapids at Fort Smith to the head of the Delta is nearly 300 km*.

Figure 25 shows a slope profile. The slope of the Lower Slave River is very flat -- only 0.033 m per km. Figure 26 shows locations and median grain sizes (D_{50}) for a series of bed and bank material samples along the river. The bed material is mainly sand, with a median size of about 0.2 mm. Cross-sectional dimensions of the channel average about 700 m wide and 7 m deep at high water (July).

Regime analysis indicates that the channel slope is more or less a bare minimum for maintenance of a mobile bed. Bed load transport can be expected to be very small except at high flow conditions.

*See Figure 17 at scale 1:200,000. In a direct line from Fort Smith to Great Slave Lake the distance is about 165 km.

Geological information on crustal rebound (Quigley, 1980; Clark and Persoage, 1970) indicates that the Slave Delta area is presently rising in relation to Fort Smith, with a differential rise in recent millennia in the order of 2 mm/yr. The question arises as to whether this might cause an appreciable loss of sediment to storage between Fort Smith and the Slave Delta. For a river length of 300 km and a width of say 1 km, the annual volume of sand accumulation in a wedge would be approximately:

$$0.5 \times 300{,}000 \times 1000 \times \frac{2}{1000} = 300{,}000\ m^3/yr$$

Since the sand fraction of the river's suspended load is about 2,000,000 m^3/yr, it appears that crustal rebound could not account for storage of a substantial proportion of transported material.

6.8 Delta Morphology Changes as Shown by Nine Sets of Aerial Photographs, 1930 - 79

Table 14 summarizes hydrologic conditions, where known, for nine sets of aerial photographs from 1930 to 1979. In assessing apparent differences between the aerial pictures of different dates, water levels in Great Slave Lake are of considerable importance because of the very low relief of the Slave Delta. Table 13 shows that the total range in water levels shown in the entire sets of aerial photographs is about 0.6 m, which could make a big difference to apparent shoreline locations. Unfortunately, recorded water levels are not available for 1930, but on the basis of a longer record for Lesser Slave Lake it is considered likely that the level was about average for the time of year. Estimates of wind set-up for a lake 50 m deep, a fetch of 160 km (from the W and NW), and a wind

velocity of 112 km/hr in the direction of the fetch, indicate a possible maximum above still lake level of about 1 m (Saville et al, 1962, p. 103).

Comparison of sets of photographs from 1930, 1946, 1960, 1966, 1970, 1973, 1979 show the following information (see Figures 26 to 37):

1930 - 1946 (Figs. 26,30,34)	The active delta apparently extended into the lake by an average distance of about 0.5 km in the Nagle Bay area (Figure 26) and 1 to 2.5 km in the East Channel/Resdelta Channel area (Figure 30).
1946 - 1960 (Figs. 27,31,35)	Much less change is evident, with local advance generally less than 0.5 km at Nagle Bay (Figure 27). The shoreline appears to have retreated, however, between the East Channel and Resdelta Channel (Figure 31).
1966 - 1970 (Figs. 28,32)	Main advance (0.5 to 1 km) appears to be concentrated around the mouth of Old Steamboat Channel (Figure 28) and west of the mouth of Resdelta Channel (Figure 32).
1960 - 1973 (Figure 36)	A slight shoreline advance is detectable at the west end of the Delta. Also, further reduction of the central channels is apparent.
1930 - 1979 (Figs. 29, 33)	Major advances in the shoreline (0.5 to 2 km) are apparent when the airphotos from 1930 and 1979 are compared.

Although there are differences in lake water level between these sets of aerial photographs, it seems questionable whether these can explain the apparent advance of the delta shoreline by 1 to 2 km between 1930 and 1946 and the much smaller change since then.

It may be that the advance between 1930 and 1946 represents an episode in a jerky process of advance. As noted by Axelsson (1967), in the presence of waves and longshore currents, deltas may exhibit

alternating constructional and destructional phases. This behaviour is clearly suggested by the indications of delta building and shoreline retrogression evident in Figure 17. The original of this figure, at a scale of 1:63,360, revealed scarplets and the downstream ends of distributaries truncated by beach ridges.

It appears that in the last several millennia there have been five major episodes of active delta building that have been terminated eventually by wave and longshore current erosion with the formation of beach ridges. Beach ridges and/or eroded shores (spits) occur on the opposite side of the main channel of the Slave River from active delta building, and the two activities take place at the same time.

Figure 37 shows the location of an outer submerged bar that appears to mark a change in slope at the delta front. Figure 37 is a print of a mosaic made from airphotos taken in July 1960.

7. CHANGES IN AQUATIC AND TERRESTRIAL VEGETATION FROM 1930 TO 1979

The effect of changing Slave Delta conditions on waterfowl and wildlife is significant to native people dependent on them for food or fur.

Changes in shoreline hydrography over time are depicted in Figures 26 to 37; these figures also show similar changes in nearshore vegetation. Inspection of Figures 26 to 33 reveals changes in vegetation between different years, with the changes outlined.

Figure 38 shows that emergent vegetation in shoal nearshore waters frequently grows in circular rings. This aquatic vegetation is likely Hardstem Bulrush (scirpus acutus), whose rhizome roots grow radially outward and deplete the fine-grained lake bottom sediments of nutrients, much as fairy rings caused by a fungus (mycellium) do in a residential lawn. Although the ring structure in the emergent vegetation is thought to result from radial impoverishment of plant nutrients, it is also possible that the roots may secrete toxic substances.

The emergent vegetation seen in Figures 26 to 38 could also be scirpus validus, but the chances of this seem less likely. If the emergent vegetation is largely scirpus acutus, the plant is 2 to 3 m high and usually grows in water depths of 1 to 2 m.

Hardstem Bulrush is a favored nesting site for several species of ducks, including cinnamon teal, gadwall, lesser scaup, and redhead -- with the latter two species more likely to be found in the Slave Delta area.

Examination of the several sets of airphotos reveals that scirpus acutus (and perhaps other species of scirpus plus duckweed, pondweed, etc.) usually grows in shoal waters of the nearshore zone -- commonly in places where the vegetation is protected from severe wave attack in the open water season and from disturbances by drift ice during spring break-up of lake ice -- in other words, in shallow bays and in lagoons behind spits and barrier islands (see Figures 26 to 33 and Figures 37 and 38).

The vegetation on both sides of Old Steamboat Channel and Nagle Channel may be used as an indication of change in terrestrial vegetation over a period of several decades. The colour photographs taken in the fall of 1966 show the typical vegetation situation bordering distributaries (see Figure 39). The yellow fall colours of balsam poplar readily distinguish it from the dark green colours of white spruce. Some of the willows and alders in the brush areas adjoining distributaries have also changed to fall colours. In Figure 39 the balsam poplar occurs in almost pure stands in small patches. A typical sequence landward from distributary shorelines is horsetail (Equisetum), willow, alder, balsam poplar on higher but moist soils, with white spruce on still higher ground above balsam poplar.

Because the highest areas are no more than 3 m above river level the area is subject to frequent flooding. Because black spruce is intolerant to flooding for periods of 30 to 40 days, there is likely very little black spruce growing on the active part of the Slave River Delta. However, this could change significantly if construction of an upstream reservoir sharply reduced flooding within the Delta. Black spruce might eventually flourish, encroach on distributary shores and "push out" the horsetail, willows, alders and balsam poplar that presently support different species of wildlife and waterfowl.

8. STUDY FINDINGS

The interpretation of nine sets of contact airphotos, several Landsat images, and several maps and reports, has resulted in a number of findings, which are itemized below:

1 In August 1975 the Slave River discharged a plume of suspended fine sediment that spread 35 km out into Great Slave Lake. This sediment was re-distributed by waves and currents over a lake area covering some 6000 km^2. In July 1980, however, the suspended sediment dispersed over 2500 km^2 of lake surface, based on evidence in Landsat images.

2 The active subaqueous delta platform extends lakeward to the delta front from the present-day shoreline. The delta front generally lies between 1 and 2 km beyond the present shoreline from Nagle Bay to a point west of Resdelta Channel. However, the delta front extends about 4 km out into Great Slave Lake opposite Resdelta Channel, recently the main distributary channel. Beyond the delta front the lake bottom would seem to drop off rapidly to depths of 10 to 30 m or more.

3 The distributary channel width at two sections on Old Steamboat Channel was reduced from 250 m to 100 m and from 250 m to 150 m between August 21, 1930, and July 10, 1973. On the other hand, at two sections on the Resdelta Channel the width of the distributary increased from 175 m to 315 m and from 200 m to 450 m between August 21, 1930, and July 10, 1973. It is expected that bankfull discharges changed correspondingly in these main distributaries, more or less as the square of width changes. Distributaries into Nagle Bay and north to the midpoint

of the active delta have continued to shrink, while at the same time Resdelta Channel has enlarged significantly.

4 Shoreline advance in the active delta region appears to be rather jerky. Episodes of rapid advance are followed by nearly stable conditions for several years -- or even by local retrogression. The rate of delta advance is also seen to vary along the length of the active delta shoreline.

5 North of Fort Smith the Slave River follows a course roughly midway between the Talston River and the Little Buffalo River. Over postglacial time active delta building appears to have alternated from one side of the main position of the Slave River to the other, especially north of latitude 61°00'. While active delta building (progradation) takes place on one side of the Slave River Lowland, the opposite side appears to undergo beach ridge or spit building accompanied by some intermittent beach erosion.

6 Sediment carried by the Slave River is generally so fine that beach ridges contain mostly fine sand, with very little if any coarse sand or gravel sizes. Most raised beach deposits in western Canada are composed of clean well graded sands with minor gravel sizes. In addition, the raised beach ridges in the Slave River Lowland are either obscure or very weakly expressed in the present-day landscape at several locations inland from the coast of Great Slave Lake.

7. Nearshore vegetation flourishes in warm, shallow, nutrient-rich waters, in sites that are more or less protected from wave

and ice action. Emergent vegetation in the quiet waters of bays and lagoons forms and eventually disappears behind spits and behind barrier islands. Thus the location of nearshore vegetation changes with changes in the morphology of the active delta. The principal emergent vegetation is thought to be Hardstem Bulrush (scirpus acutus).

8 The gradient on the Slave River is thought to have flattened over postglacial time, owing to differential isostatic rebound following deglaciation, and to longtime delta front progradation over the last roughly 10,000 years. Taking an average shoreline advance of 1½ km over 50 years (Sawmill Channel to Resdelta Channel over the interval), the distance of shoreline advance over postglacial time (10,000 years) is 300 km. This 300 km figure corresponds to the river length from the lower end of Smith Rapids to the present shore of the delta at Great Slave Lake, which is about twice the direct distance between these same points.

9 The rate of delta advance could have been greater during the first several years after deglaciation because there is very little evidence of beach ridge building between latitude 60° and latitude 61°. After the delta front reached latitude 61°, however, the process of delta advance seems to have been more erratic, with more frequent episodes of shoreline stability and/or local retrogression alternating with episodes of delta progradation on the opposite side of the Slave River Lowland.

10 Slave Lake is deep (up to 614 m at its deepest) and covers some 28,400 km^2, much of the sediment transported is fine (silt/clay), the steeply sloping delta front is situated quite close to

the present shoreline (note that it is even much closer in the inactive delta portion), and wave and current action are strong. All these factors cause fine sediment to be carried far out into the lake, where it settles very slowly to the lake bottom.

11 Fluctuating water levels in delta distributaries could become more regulated in the future with construction of a dam at or near Mountain Rapids. If distributary water levels become stabilized, with very little or no active delta flooding in the future, the result could have a significant effect on wildlife that depends on horsetail, willows, alders, and balsam poplar growing along or near the shores of distributaries. With the reduction in delta flooding, black spruce, which is very intolerant to flooding for extended periods, may eventually encroach upon the shore, "pushing out" the vegetation that is now used by waterfowl, muskrat and beaver. In other words, flooding of the delta in the spring and slow drainage of the flood waters out of sloughs in distributaries, marshes, and swamps for the rest of the year would seem to be a desirable consequence for the support of wildlife in the Delta area.

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The three oblique photographs at the end of this report were taken from the air by Northwest Hydraulic Consultants Ltd. in July 1980.

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January 22, 1981

Northwest Hydraulic Consultants Ltd.
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ATTN:E.K. Yaremko

re: Use of Slave River Hydro Feasibility
Study Data

Dear Sir;

With reference to your letter of January 21, 1981 regarding the use of information generated in the Slave River Hydro Feasibility Study for your studies of the Great Slave Lake delta, this is entirely in line with Alberta Environment policy. We would appreciate receiving a statement of the information you use however, for our records and would expect that relevant information generated through your study of the Great Slave Lake delta be made available to the Slave River study.

Yours truly,

R.L. Walker & Partners Ltd.

M.C. Swales

Dr. M.C. Swales
Resident Manager
MCS/jb
c.c. Carl Primus

TABLE I.

Daily mean, maximum, and minimum temperatures, total precipitation, and rainfall at selected stations, 1931-60

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature, F														
Daily mean	Fort Smith	-13.8	- 8.0	6.1	27.0	45.6	55.3	61.6	57.5	46.2	32.3	11.0	- 6.3	26.2
	Fort Resolution[1]	-14.9	-10.4	1.9	22.0	42.0	52.9	60.2	57.5	45.7	31.6	12.4	- 7.1	24.5
	Hay River	-12.2	- 7.8	3.8	23.6	40.8	51.6	59.8	57.7	46.8	33.1	11.2	- 6.2	25.2
Daily maximum	Fort Smith	- 4.5	2.8	18.3	38.8	57.4	67.9	73.8	69.9	56.0	40.1	18.4	2.3	36.7
	Fort Resolution	- 7.3	- 2.1	11.4	31.9	52.0	62.8	69.1	65.6	52.4	36.7	18.2	- 0.4	32.5
	Hay River	- 3.2	2.2	14.4	33.8	50.2	61.4	69.0	66.9	54.6	39.7	18.2	2.3	34.1
Daily minimum	Fort Smith	-23.0	-18.7	- 6.2	15.1	33.7	42.7	48.4	45.3	36.4	24.5	3.5	-14.9	15.6
	Fort Resolution	-22.4	-18.6	- 7.7	12.0	31.9	43.0	51.3	49.3	38.9	26.5	6.6	-13.8	16.4
	Hay River	-21.2	-17.8	- 6.9	13.3	31.3	41.8	50.6	48.3	39.0	26.4	4.1	-14.6	16.2
Precipitation, inches														
Total	Fort Smith	0.61	0.68	0.75	0.65	1.02	1.21	2.10	1.36	1.66	1.16	1.03	1.03	13.28
	Fort Resolution	0.46	0.52	0.37	0.47	0.78	0.97	1.33	1.36	1.64	1.34	1.52	0.79	11.55
	Hay River	0.63	0.60	0.58	0.64	0.93	0.98	1.66	1.47	1.55	1.38	1.32	0.90	12.59
Rain	Fort Smith	0.01	T[2]	0.1	0.17	0.91	1.21	2.10	1.36	1.53	0.44	0.04	0.01	7.76
	Fort Resolution	0.00	T	T	0.13	0.69	0.97	1.33	1.36	1.53	0.54	0.01	T	6.56
	Hay River	0.01	0.01	T	0.19	0.78	0.95	1.61	1.47	1.49	0.70	0.04	0.01	7.26

[1] 22 years, 1931-60
[2] Trace

(modified from Doy, p13)

TABLE I

Variable	Delta plain	
	Rate of growth is slow	fast
Wave energy	high	low
Tidal regime	high	low
Offshore gradient	high	low
Rate of vegetation growth	low	high
Crustal subsidence	high	low
Sediment input	low	high

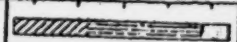
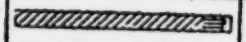
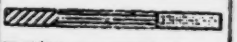
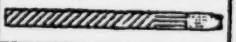
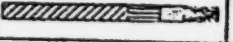
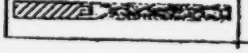
TABLE 2 Variables influencing the rate of delta front growth (from Ritchie and Brunsden, p. 68)

RIVER REGIME (Variations influence sediment load and transport capacity	Flood stage	Sediment load	Quantity of suspended load and bed load (that is, stream capacity) increases during flood
		Particle size	Particle size of suspended load and bed load (that is, stream competence) increases during flood
	Low river stage	Sediment load	Stream capacity diminishes during low river stage
		Particle size	Stream competence diminishes during low river stage
COASTAL PROCESSES	Wave Energy		High wave energy with resulting turbulence and currents erode, rework, and winnow deltaic sediments
	Tidal range		High tidal range distributes wave energy across an extended littoral zone and creates tidal currents
	Current strength		Strong littoral currents, generated by waves and tides, transport sediment alongshore, offshore, and inshore
STRUCTURAL BEHAVIOR (With respect to sea level datum)	Stable area		Rigid basement precludes delta subsidence and forces deltaic plain to build upward as it progrades
	Subsiding area		Subsidence through structural downwarping coupled with sediment compaction allows delta to construct overlapping sedimentary lobes as it progrades
	Elevating area		Uplift of land (or lowering of sea level) causes river distributaries to cut downward and rework their sedimentary deposits
CLIMATIC FACTORS	Wet area	Hot or warm	High temperature and humidity yield dense vegetative cover, which aids in trapping sediment transported by fluvial or tidal currents
		Cool or cold	Seasonal character of vegetative growth is less effective in sediment trapping; cool winter temperature allows seasonal accumulation of plant debris to form delta plain peats
	Dry area	Hot or warm	Sparse vegetative cover plays minor role in sediment trapping and allows significant aeolian processes in deltaic plain
		Cool or cold	Sparse vegetative cover plays minor role in sediment trappings; winter ice interrupts fluvial processes; seasonal thaws and aeolian processes influence sediment transportation and deposition

TABLE 3 Factors influencing deltaic sedimentation. These factors refer not only to large deltas built into the ocean, but also to large deltas built into large present-day lakes (from Morgan, p. 33).

Environment of deposition	*Deposit*	*Origin reflected in typical stratigraphical position*
Channel floor	Channel-lag deposit	Channel or substratum deposits
Point bar	Point bar deposit	
Channel bar	Channel bar deposit	
Point bar swale or in abandoned braided stream channel	Swale-fill deposit	
Levee	Levee deposit	Overbank or topstratum deposits
Crevasse-splay	Crevasse-splay deposit	
Floodbasin	Floodbasin deposit	
Within abandoned or decaying channel	Channel-fill deposit	Transitional deposit

TABLE 4 Classification of alluvial deposits in subenvironments along the lower reaches of a meandering river, and their origin as reflected in their typical stratigraphical position (from Allen, 1965, p. 128).

DEPOSITIONAL TYPES	LITHOLOGY PERCENT 0 25 50 75 100	REMARKS
NATURAL LEVEES		Deposited in narrow bands flanking the Mississippi River and its abandoned courses and distributaries. Elevation varies from 35 feet near Baton Rouge to sea level.
POINT BAR		Usually found flanking the more prominent bends of present and abandoned courses. Thickness in excess of 100 feet.
PRODELTA CLAYS		Fat clay in offshore areas and at depth beneath deltaic plain. Thickness ranges between 50 and 400 feet.
INTRA DELTA		Coarse portion of subaqueous delta. Intricately interfingered deposits. Disposed in broad wedges about abandoned courses and major distributaries.
INTERDIS-TRIBUTARY		Forms clay wedges between major distributaries. Minor amounts of silts and fine sands typically occur in very thin but distinct layers between clay strata.
ABANDONED DIS-TRIBUTARY		Form belts of clayey sediments from a few feet to more than 1000 feet in width and from less than 10 to more than 50 feet in depth.
ABANDONED COURSE		Form belts of fairly coarse sediment in abandoned Mississippi River courses. Lower portion filled with sands, upper portion with silts and clays. Coarsest fill near point of diversion.
SWAMP		Tree-covered organic deposits flanking the inner borders of the marsh and subject to fresh-water inundation. Deposits 3 to 10 feet thick.
MARSH		Forms 90 percent of land surface in the deltaic plain. Ranges from watery organic ooze to fairly firm organic silts and clays. Average thickness 15 feet.

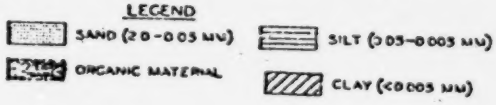


TABLE 5 Summary of depositional types within the deltaic plain (left) and typical associated properties (right). The above grain size distributions are probably quite similar to those in depositional features (subenvironmental sediments) on the modern Slave Delta. Note that point bars and distributary beds are coarsest and that the finest material is prodelta (lake-bottom) clays, with slightly coarser sediments in interdistributary floodbasins (bays in addition to marshes and swamps), which contain considerable organic matter. Natural levees, crevasse splays are intermediate in composition between point bars and channel beds on the one hand and prodelta clays and interdistributary floodbasins and bays. Compare with textural characteristics of three microlandforms shown in Figure 16. (From Kolb and Van Lopik, p. 58).

Table 6 Comparison of the Slave, Athabasca, and Mackenzie Deltas

Characteristic	Slave	Athabasca	Mackenzie
Morphologic type	Arcuate	Birdfoot	Estuarine
Mean water inflow, km^3/yr	118	23	350
Mean sediment inflow, $10^6 t/yr$	30	8	150
Ratio sediment/water, $10^6 t/km^3$	0.25	0.35	0.43
Approx. area, km^2	640	1730	12800
Ratio area/sediment, $km^2/10^6 t$	21	216	85
% sand in sediment inflow	10	20	10
Approx. depth of water at delta front, m	30	3	10

Table 7. Great Slave Lake Water Level Statistics
(based on period 1938-79)

Mean annual maximum	156.9 m
Mean annual minimum	156.4 m
Mean annual range	0.5 m
Highest in period (in 1962)	157.3 m
Lowerst in period (in 1947)	156.3 m
Historic range	1.2 m

Table 8. Comparison of Great Slave Lake Levels Over Three Periods

	Mean Annual Max.		Mean Annual Min.		Difference
Period	No. of Data	Lake Elev. (m)	No. of Data	Lake Elev. (m)	(Mean annual range) (m)
1934-67	31	156.93	31	156.38	0.55
1968-71*	4	156.74	4	156.27	0.47
1972-79	8	156.92	7	156.44	0.48

*Period of filling Williston Reservoir on Peace River.

Table 9. Great Slave Lake Wave Statistics Off Hay River, 1975

Statistic	Height (m)	Period (secs)
Maximum	4	8
Exceeded 10% of time	1	5.5
Exceeded 50% of time	0.5	3.5

Table 10. Slave River Flow Statistics

Mean flow (1960-67 & 1972-79)	3700 m^3/s
Mean annual maximum (29 years)	7200 m^3/s
Mean annual minimum (24 years)	1200 m^3/s
Highest recorded (1974)	11200 m^3/s
Lowest recorded (1953)	530 m^3/s

Table 11. Ranges of Flow in Delta Distributaries

Channel	Station number in Figure 6	Approx. range of flows 1978-79 (m^3/s)
Jean River	2	20 - 130
Nagle Channel	3	2 - 35
Old Steamboat Channel	5	10 - 130
West Channel	4	1 - 130
Middle Channel West	6	70 - 350
Middle Channel East	7	1 - 100
East Channel	8	1 - 130
Resdelta Channel	9	1500 - 6500

TABLE 12

DISTRIBUTION OF SLAVE RIVER SUSPENDED SEDIMENT LOAD BY MONTHS

MONTH	PERCENTAGE OF ANNUAL LOAD
January	0.8
February	0.7
March	0.7
April	0.7
May	15
June	27
July	27
August	14
September	6.9
October	4.8
November	1.6
December	0.8

TABLE 13

PROMINENT FEATURES OF THE PEACE AND SLAVE RIVERS

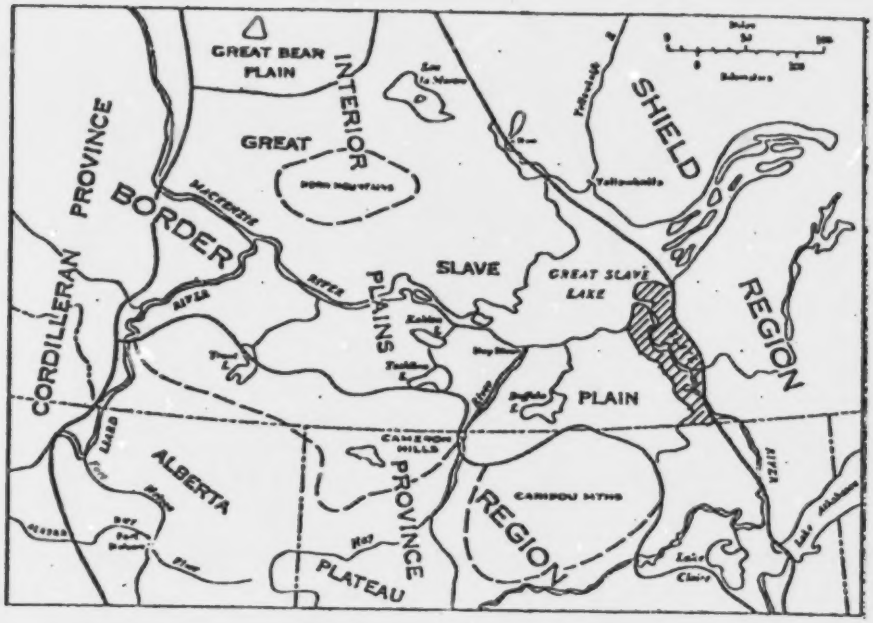
KILOMETER DISTANCE[1]	GEOGRAPHIC LOCATION	MAJOR TRIBUTARIES	CHANNEL SLOPE[2]	CHANNEL FEATURES	DRAINAGE FEATURES	DRAINAGE AREA (km^2)
0	Peace Point			River meanders through the alluvial deposits of the Peace Delta. Numerous alluvial islands and channel bars.	Minor drainage from the flat terrain of the Peace Delta. Plus two major outflow channels from Lake Athabasca.	293,000
84	Rocky Point	Chenal Des Quatre Fourches	5.0×10^{-5}			
100	Start of Slave River	Riviere Des Rochers	———	River dominated by the western margin of the Canadian Shield that restricts the movement of the river. Numerous rocky islands and banks (some banks of sedimentary origin on the west side), minor rapids, active channel bars.	Minor drainage from the Canadian Shield to the east and from the Great Slave Plain to the west.	
156		Murdock Cr.				
158		La Butte Cr.	4.3×10^{-5}			
165	May Camp	Bocquene R.				
213	Fitzgerald		———	River drops over four sets of major rapids. The last presence of the Canadian Shield.		606,000
215		Dog River	1.3×10^{-3}			
240	Fort Smith		———			
250	Bell Rock/Cunningham Landing			The last outcrops of rock (sedimentary) occur at Bell Rock/ Cunningham Landing. Downstream the river meanders through alluvial deposits. There is probably a geomorphic explanation for the extremeness of the Grand Detour meander. Channel bars and islands are continually eroding and forming. Moderate bank erosion in places. The Slave Delta has little relief. The most northerly channel (Resdelta Ch.) conveys most of the flow.	Apart from the Salt River which drains part of the Salt Flats of the Great Slave Plain, there is minimal surficial drainage in this reach.	
263		Salt River				
293	Start of Grand Detour		3.3×10^{-5}			
383	Outlet of Rock Lake (Landry Creek)					
497	Outlet of Ring Lake					
513	Jean River Divergence					
525	Hogle Channel Divergence					
528	Head of Slave Delta					
539	Great Slave Lake					609,000

1 Distances are river kilometers downstream of Peace Point on the Peace River, see Figure
2 Slope refers approximately to average flow conditions.

TABLE 14

HYDROLOGIC CONDITIONS CORRESPONDING TO 9 SETS OF AERIAL PHOTOGRAPHS

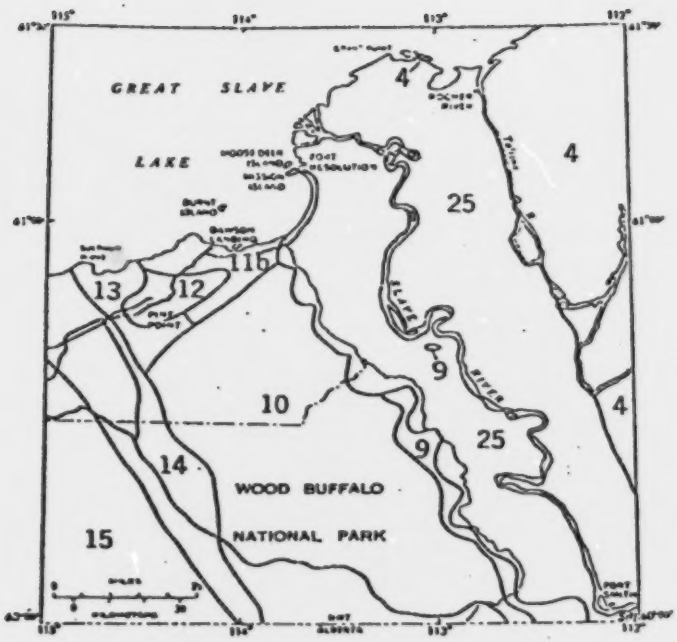
Date of photography	Level of Great Slave Lake m	Flow in Slave River m^3/s	Sediment in Slave River tonnes/day
21 Aug. 1930	157.0 (est'd)	--	--
11 July 1946	156.57	--	--
4 Aug. 1954	157.02	5360	--
27 Sept. 1957	157.05	4320	--
21 July 1960	157.06	6910	--
Sept. 1970	156.46	2920	--
16 Sept 1966	--	--	--
10 July 1973	156.79	5660	158,000
16 July 1979	156.98	5990	--



Physiographic divisions of the southwestern part of the Northwest Territories. (from Day, p 10)

Slave River Lowland

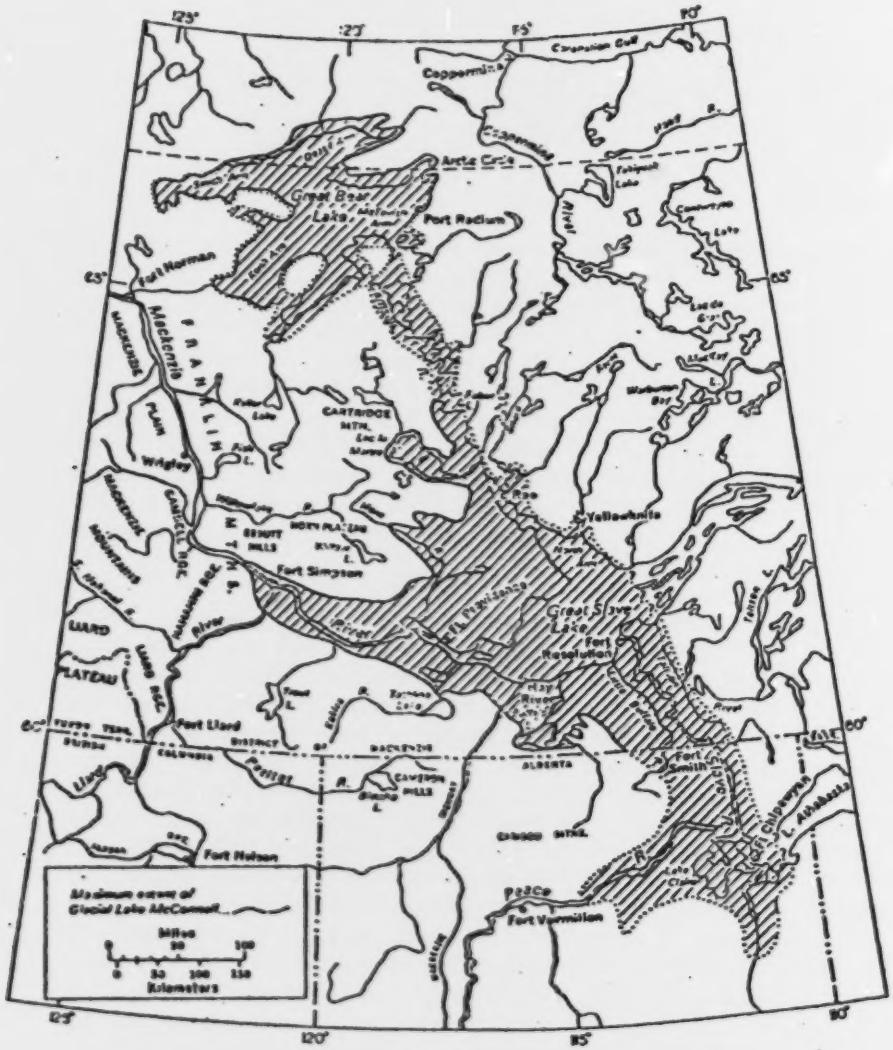
FIGURE 1



Map of geological formations in the southwestern part of the Northwest Territories (from Day, p 15)

Age	*Map unit*	
Archaean	*4*	Granite, granodiorite, quartz diorite, gneiss, chloritized granite
Palaeozoic	*9*	Middle Devonian Gypsum, salt, limestone, breccia
	10	Middle Devonian Units 11-13 undifferentiated
	11b	Middle Devonian Pine Point formation Fine-grained vuggy dolomite
	12	Middle Devonian Presqu'ile formation Coarse-grained vuggy dolomite
	13	Middle Devonian Fine-grained limestone and shale
	14	Middle Devonian Fine-grained limestone
	15	Upper Devonian Shale, limestone, sandstone
Cenozoic	*25*	Pleistocene and recent deposits

FIGURE 2



Glacial Lake McConnell (from Day, p17)

KEY MAP SHOWING GLACIAL LAKE McCONNELL

FIGURE 3

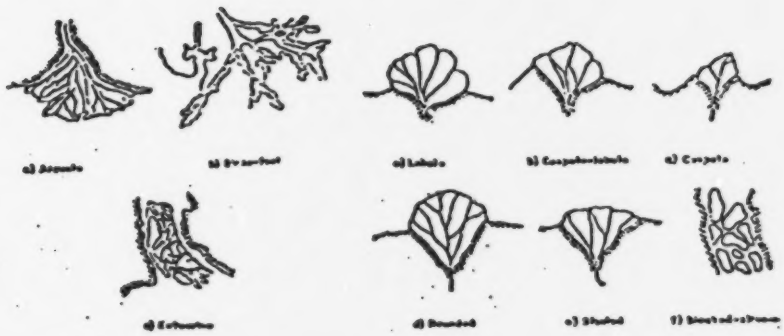
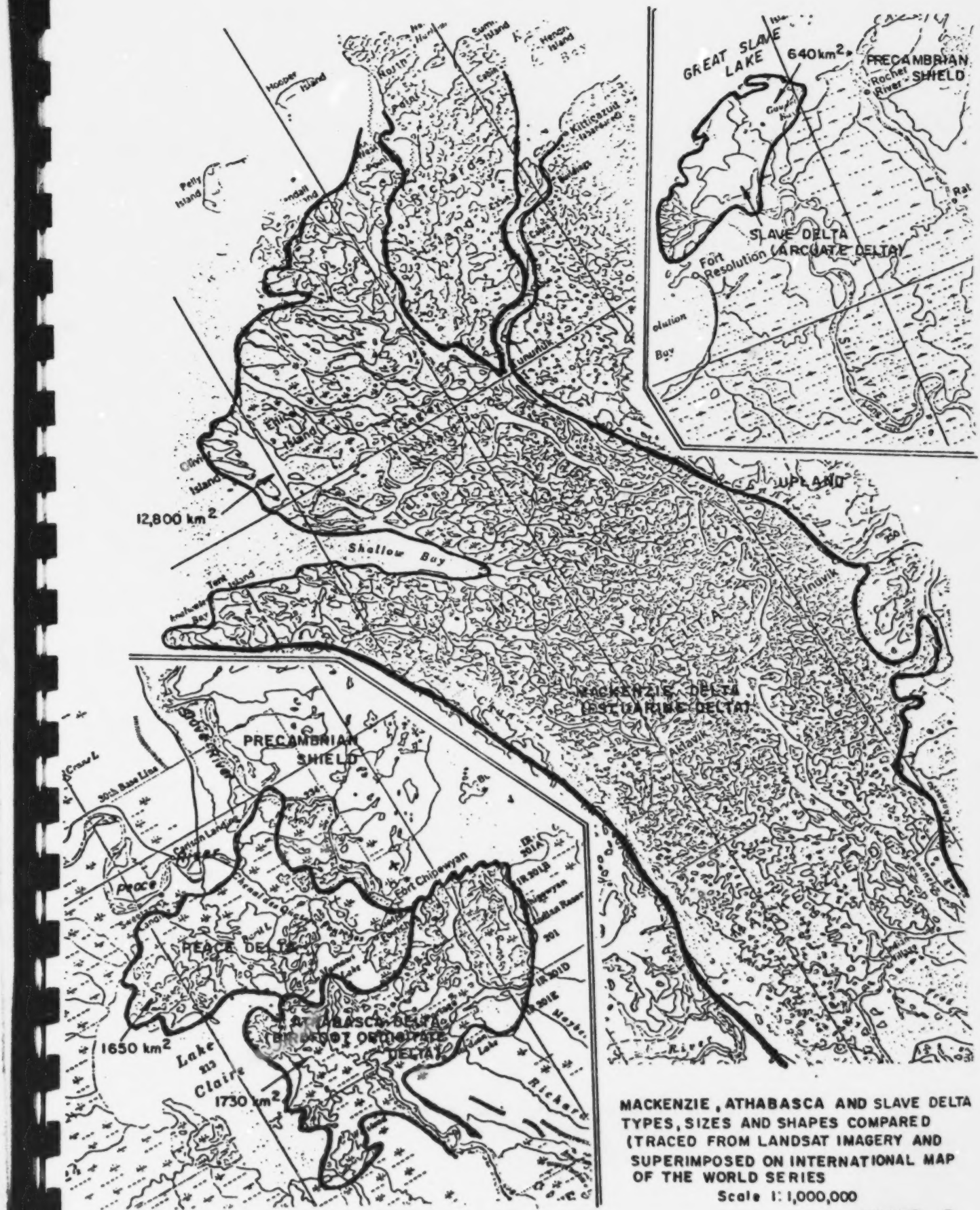


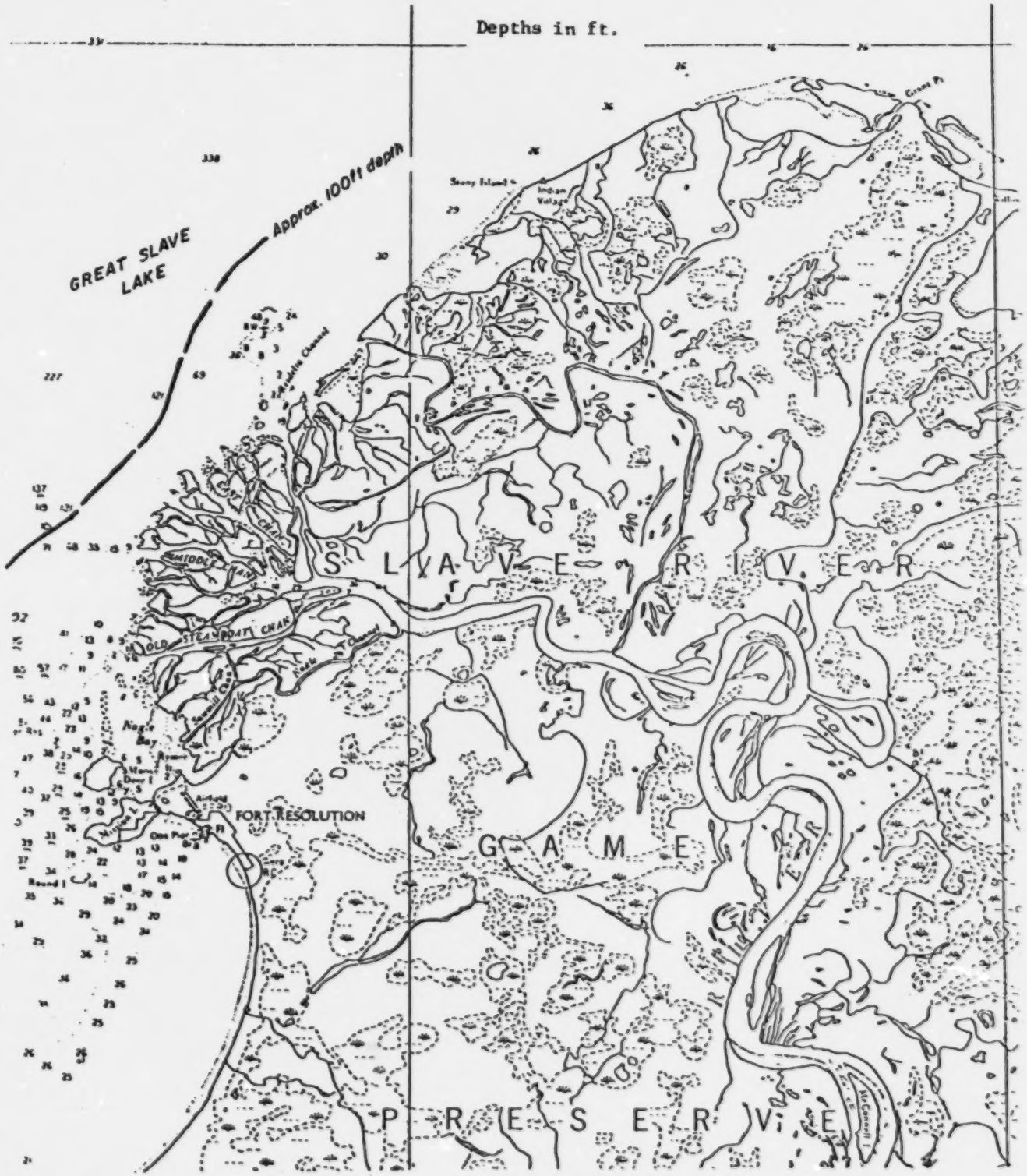
Figure 5 The left side of Figure 5 shows three basic delta types: a) arcuate, b) birdsfoot or digitate, and c) estuarine. These three types correspond to the three major deltas in the Mackenzie -- namely, the Slave delta (arcuate), the Athabasca delta (birdsfoot), and the Mackenzie delta (estuarine). The arcuate variety is a series of splitting (braiding) distributaries branching outward from a head of passes. The birdsfoot is a series of distributaries projecting out into shallow water, like the fingers of a hand. The estuarine delta is a soft sedimentary filling in an embayment or valley that extends inland from the ocean or lake. It is usually long and narrow and is bordered by higher ground on both flanks.

The right side of Figure 5 shows effects of the interaction of a river transporting sediment, on the one hand, and waves and currents (and also, in some cases, changes in lake level, i.e. a rising or subsiding shore), on the other. At lobate delta fronts (a), river sedimentation dominates. At cuspate delta fronts (b), river sedimentation or progradation dominates but wave and longshore current action modifies (erodes) the lobes. At cuspate delta margins (c), wave and currents are strong enough to trim the delta sides to a point. At rounded delta outlines (d), longshore currents smooth out the advancing delta front. At stunted shapes (e), river sedimentation and shoreline erosion processes both have moderate influences. In the case of a blocked stream (d), the shoreline is not extended into the lake or sea; here waves and currents erode and carry the sediment away as fast as it is deposited. Most of the sediment is fine, and is carried out into the lake many kilometers beyond the shoreline. (After Silvester et al, p. 203).



MACKENZIE, ATHABASCA AND SLAVE DELTA TYPES, SIZES AND SHAPES COMPARED (TRACED FROM LANDSAT IMAGERY AND SUPERIMPOSED ON INTERNATIONAL MAP OF THE WORLD SERIES
Scale 1: 1,000,000

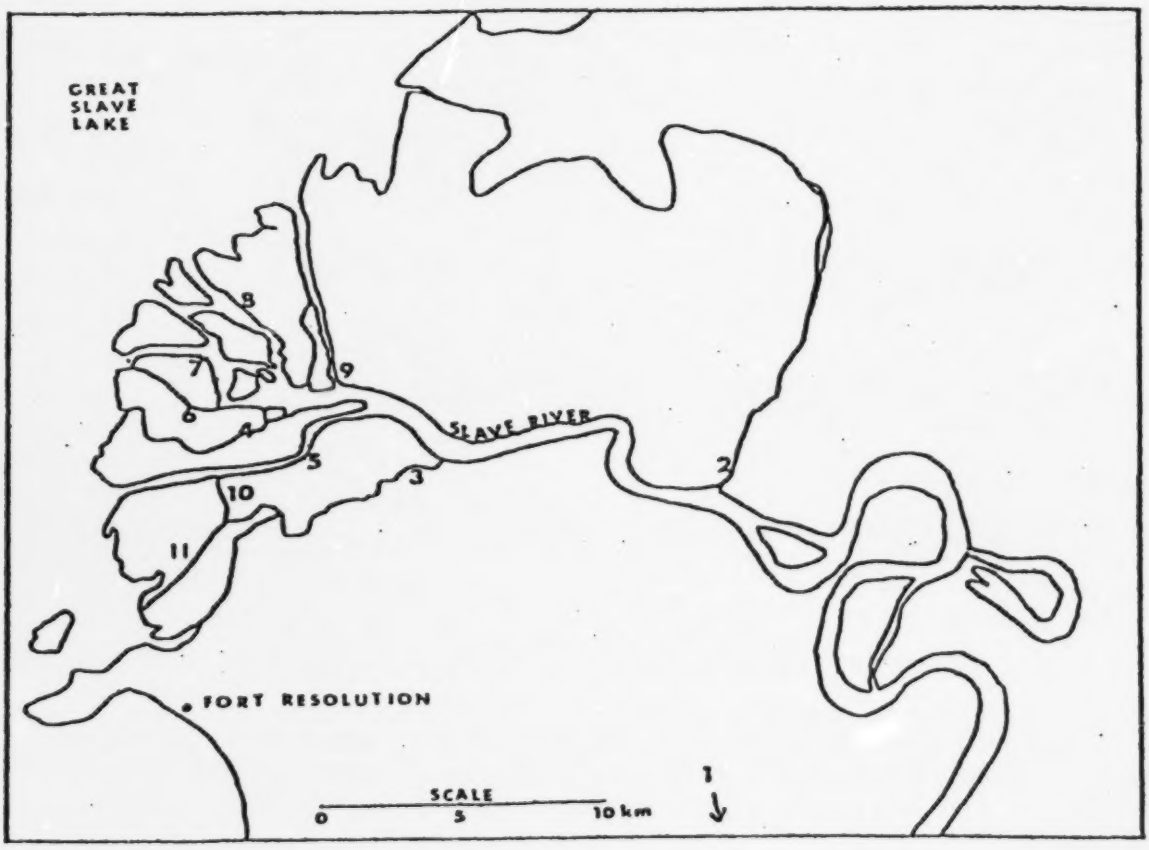
FIGURE 5



MAP OF THE SLAVE DELTA, FROM CANADIAN HYDROGRAPHIC SERVICE CHART 6370

SCALE 1:250,000

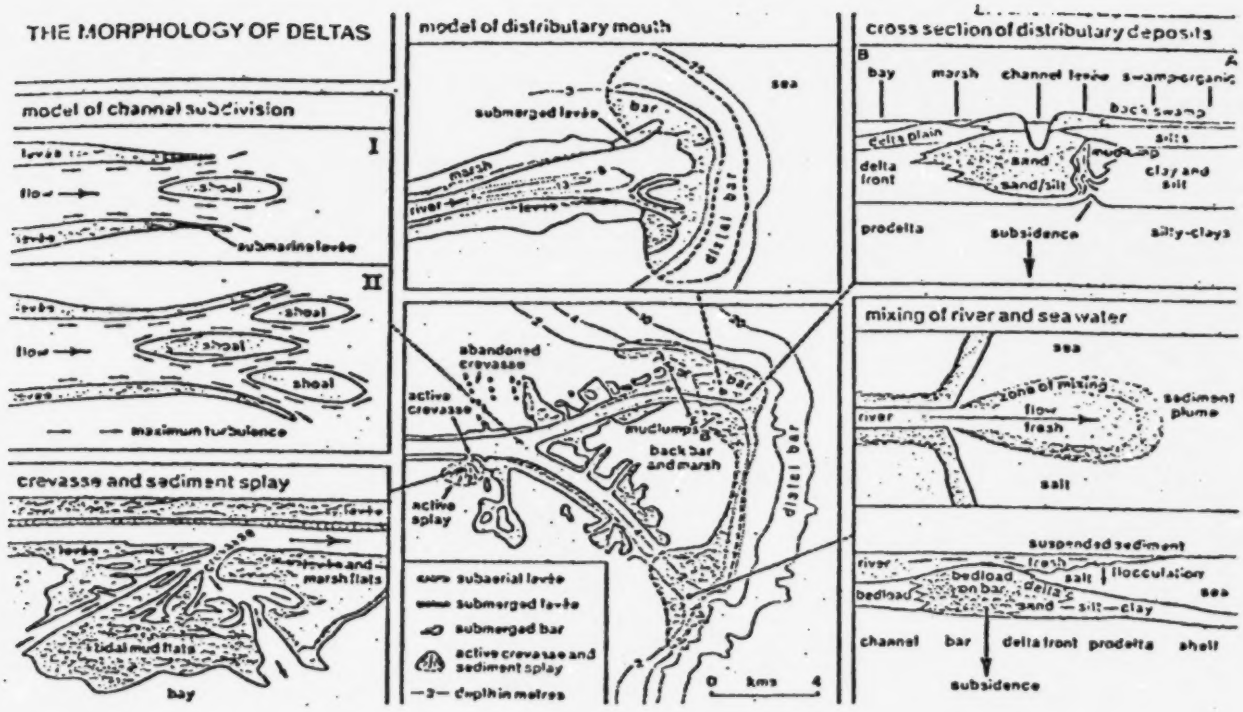
FIGURE 6



1. Slave River at Bell Rock
2. Jean River below Slave River
3. Nagle Channel below Slave River
4. Slave River West Channel
5. Slave River Old Steamboat Channel near Ft. Resolution
6. Slave River Middle Channel West
7. Slave River Middle Channel East
8. Slave River East Channel
9. Slave River Resdelta Channel
10. Slave River West Channel from Old Steamboat Channel
11. Sawmill Channel

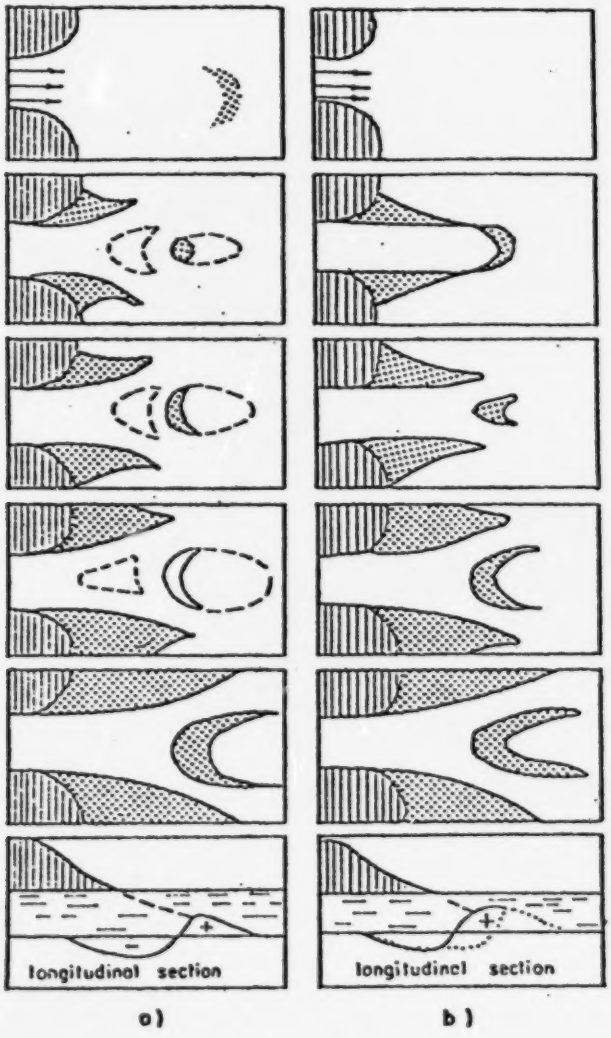
WATER SURVEY OF CANADA GAUGING STATIONS ON DISTRIBUTARY CHANNELS(1970-80)

FIGURE 7



SEQUENCE OF SIX SMALL-SCALE DIAGRAMS ILLUSTRATING THE MORPHOLOGY AND GENETIC MODELS, INTERACTING FLUVIAL AND LAKE OR SEA PROCESSES, AND SEDIMENTS FORMED IN MANY LARGE DELTAS (from Ritchie and Brunsden, p71)

FIGURE 8



TWO WAYS IN WHICH BARS FORM IN FRONT OF RIVER MOUTHS. BOTH TYPES OF BAR FORMATION CAN BE SEEN ALONG THE SHORELINE OF THE SLAVE RIVER DELTA (from Thakur and MacKay, p9)

FIGURE 9

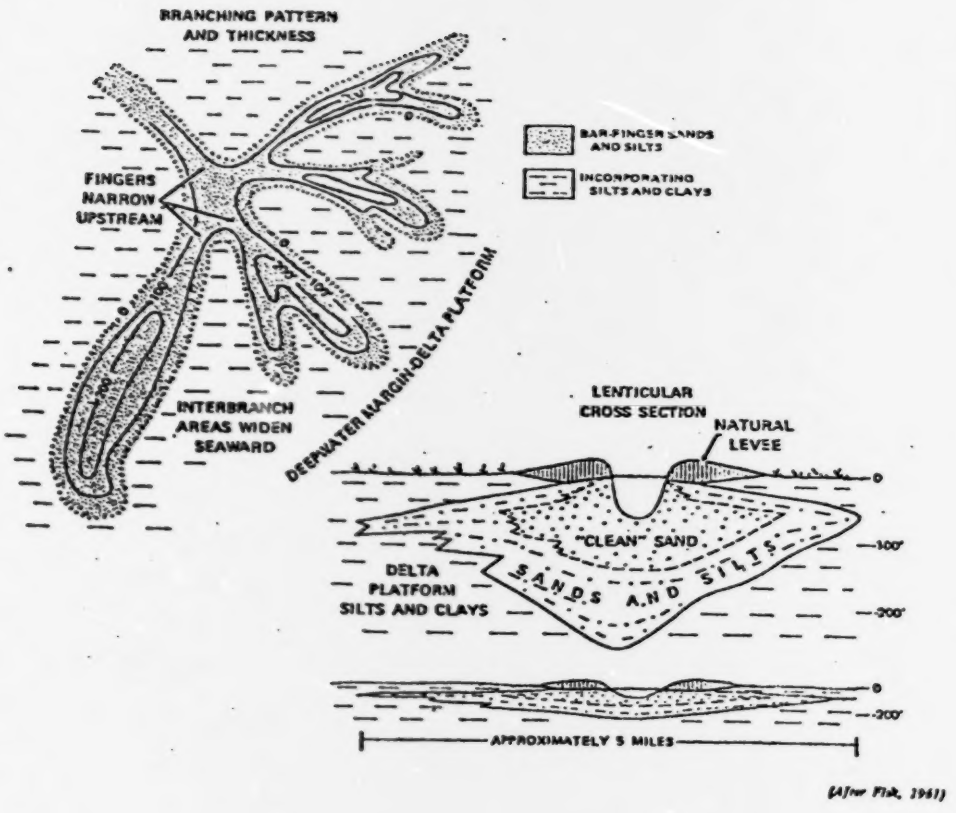


Figure 10 Distinguishing geometric and sedimentary characteristics of bar finger sands. Note that bar finger sands are among the coarsest and cleanest sediments in deltas, and commonly sink into soft underconsolidated underlying delta platform silts and clays (from Gould, p. 29, after Fisk, 1961).

FIGURE 10

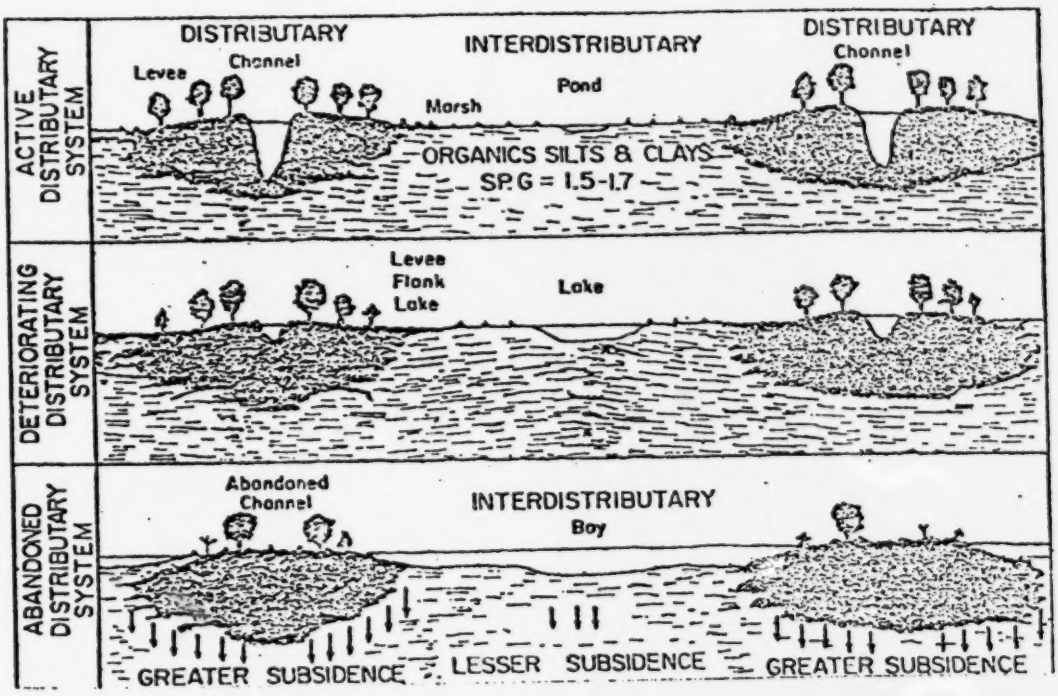


Figure 11 Effects of deltaic subsidence during distributary system formation and abandonment. Inspection of nine sets of aerial photographs between 1930 and 1979 reveals initially well-expressed levees outlined by better drainage and taller woodland vegetation. As the distributaries are abandoned (i.e. no longer active or only sporadically active), they shrink rapidly in size. They are commonly referred to as moribund serpentine distributaries, as moribund refers to the state of dying or approaching death -- hence shriveling in size. The coarser levees, usually normally consolidated or slightly overconsolidated from desiccation, commonly subside slowly into the soft, usually underconsolidated, organic silts and clays below (from Thakur and Mackay, p. 13).

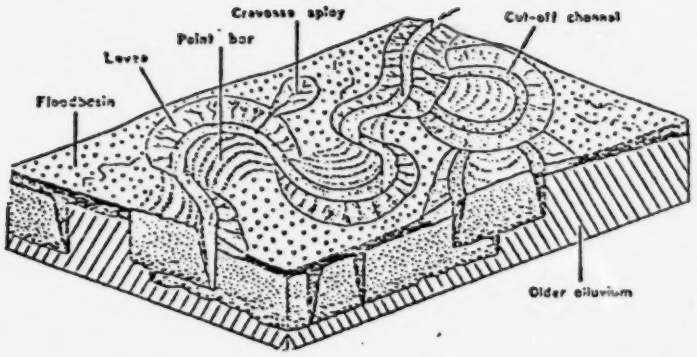


FIGURE 12 Terminology of alluvial deposits formed along a low gradient meandering stream transporting fine sand, silt,and clay particles (from Allen, 1970, p. 141).

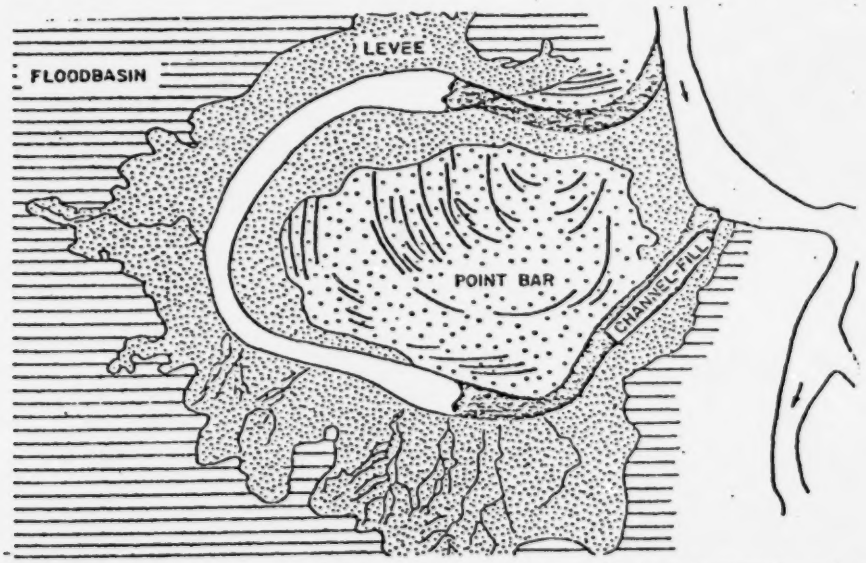


FIGURE 13 Enlarged view showing the development and abandonment of a meander loop and associated deposits formed in different environments (from Allen, 1965, p. 122).

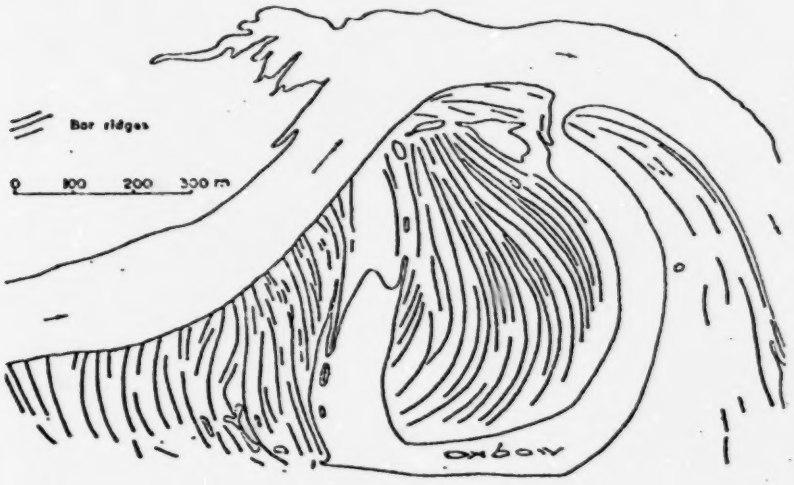


FIGURE 14 Typical accretion topography on point bars on the scroll plain adjoining the Slave River (from Allen, 1965, p. 116).

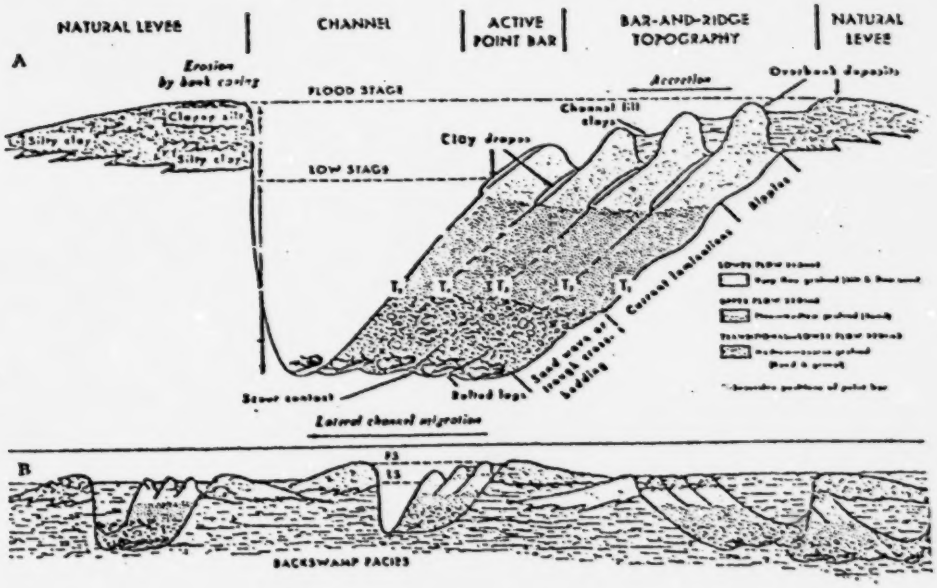
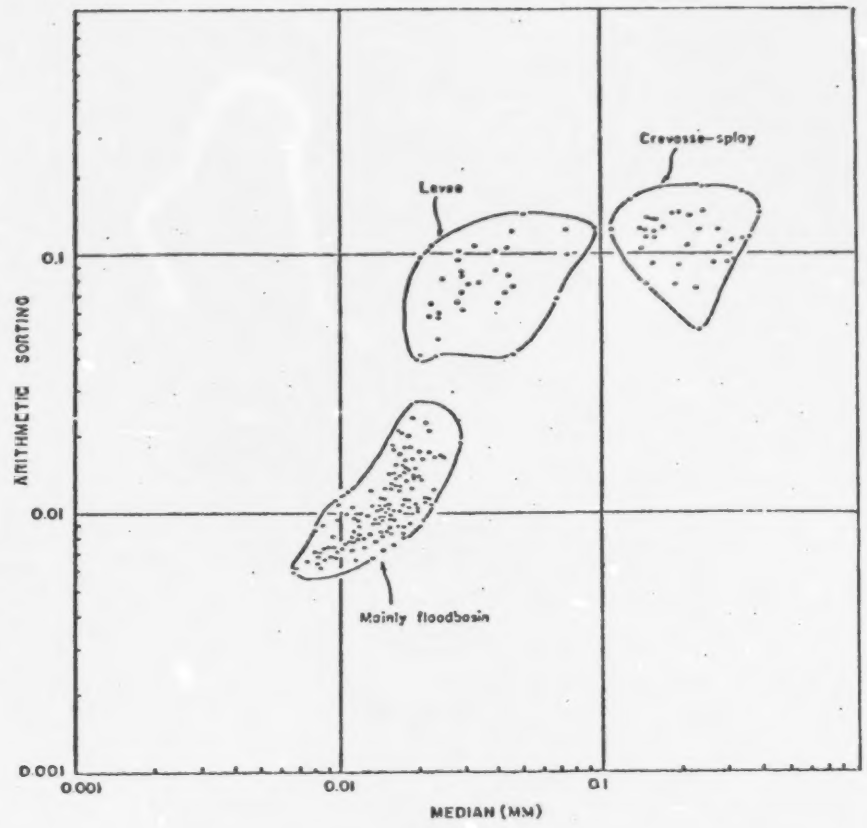


FIGURE 15 Cross sectional views showing the internal structure, mechanical composition, and formation processes associated with accretional topography (from Orr and Quick, p. 348).



Textural characteristics of topstratum deposits. Note the floodbasin deposits are mostly silt and finer materials, whereas natural levees are silt and very fine sand and crevasse (sediment) splays consist of fine sand (from Allen, 1965, p. 151).

FIGURE 16

GEOMORPHOLOGY AND DEPOSITIONAL ENVIRONMENTS
(LANDFORMS AND MATERIALS)
SLAVE RIVER PLAIN AND SLAVE DELTA, NORTHWEST TERRITORIES

See figure 17b for legend

FIGURE 17a

GEOMORPHOLOGY AND DEPOSITIONAL ENVIRONMENTS
(LANDFORMS AND MATERIALS)
SLAVE RIVER PLAIN AND SLAVE DELTA, NORTHWEST TERRITORIES

10 Actively forming sand spits and nearshore sand bars

9 Modern delta of Slave River and beaches and adjoining land below the shore of Great Slave Lake (shorezone flats). The Slave Delta consists of natural levees, sediment (crevasse) splays, subdeltas, active and abandoned distributaries with or without sloughs and marshy and swampy interdistributary floodbasins. Mostly silt and clay with some fine sand. Extensive marshy and swampy wetland

8 Lateral accretion topography (scrolled alluvial plain) adjoining the Slave River and major distributaries, commonly abandoned and branching off the Slave River. Sloughs occupy the lower parts of swales. Mainly fine sand, silt,and clay particles (medium textures) in point bars with organic deposits in swales

7 Low terraces along the Tethul and Talston River valleys. Mostly sand and silty sand

6 Wave-modified platform surrounding raised areas of limestone, with or without a capping of till. Mainly gravelly sand to silty sand (coarse textures)

5 Multiple, raised (abandoned) beach ridges splaying outward toward the east and northeast as a result of waves and longshore currents driven by westerly and northwesterly winds. Reworked deltaic deposits. Temporary abandonment of delta progradation. Alternate shoreline erosion and deposition, with wave and current erosion dominant. Indistinct wave and current eroded scarplets in some places. Mainly fine sand with some medium sand (coarse textures)

4 Lacustrine plain composed of offshore, deepwater deposits. Commonly patterned with abandoned distributaries (moribund serpentine distributary channels). Evidence of past overbank flooding and deposition of postglacial alluvial and lacustrine sediments. Mainly silt and clay with extensive, generally thin, organic deposits at the surface (fine textures)

3 Lacustrine plain composed of nearshore deposits. Mainly fine sand, very fine sand and silt, with scattered patches of organic deposits (medium textures)

2 Raised ("fossil") delta at Fort Smith, built, possibly 10,000 years ago, into glacial Lake McConnell. Mainly fine sand with some medium sand and silt (coarse textures)

1 Small mesalike areas composed of wave-modified limestone bedrock, with or without a capping of glacial till. Former islands in a large lake shrinking in size. Mainly gravelly sand

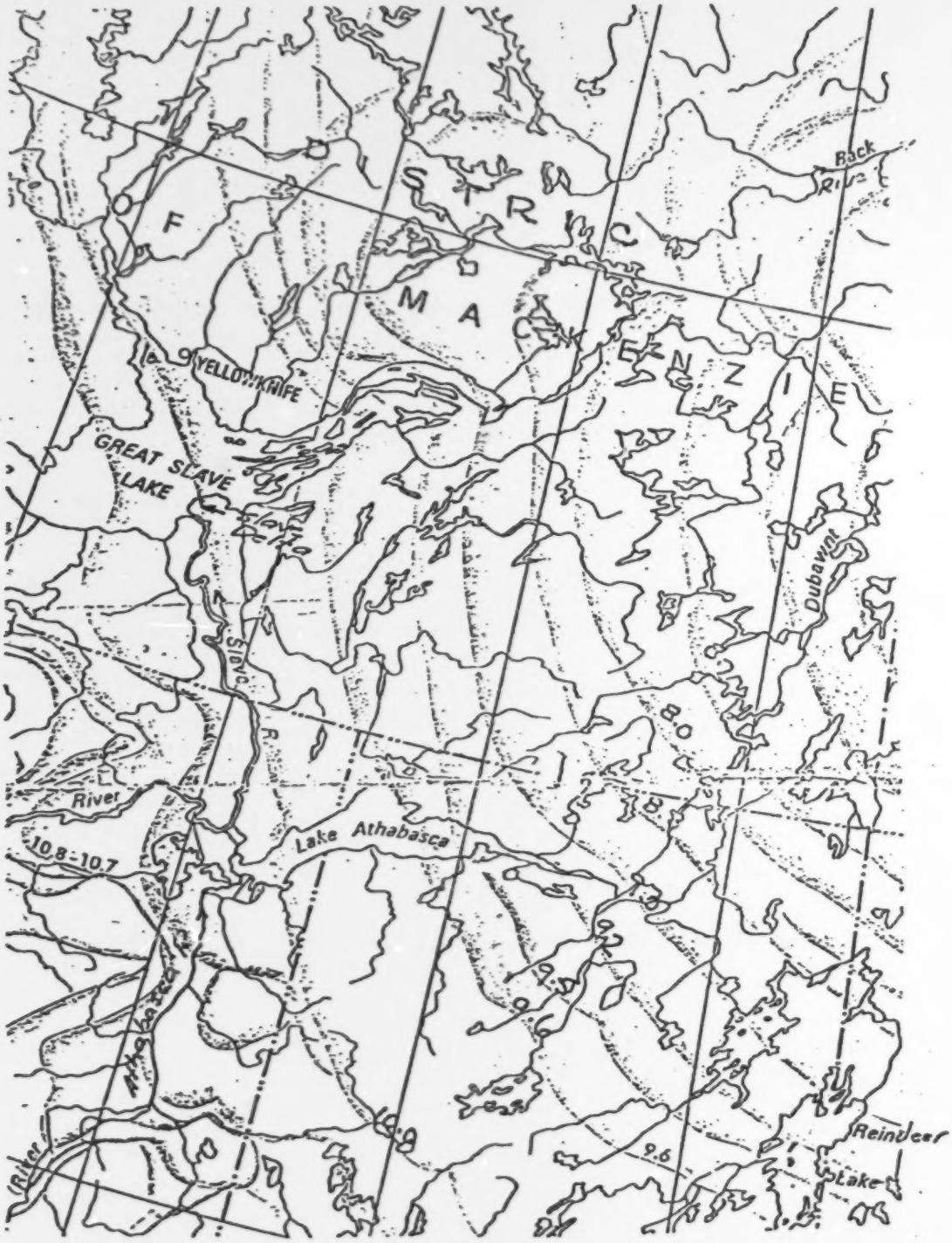
GRAPHICAL SYMBOLS

Direction of longshore current (shown on landward side of raised beach ridges)(unit 5)

Direction of generally east-west serpentine creek channels; located basinward and roughly parallel to multiple raised beach ridges

Location of discontinuous abandoned distributary channels, originating from overbank flooding of the Slave River

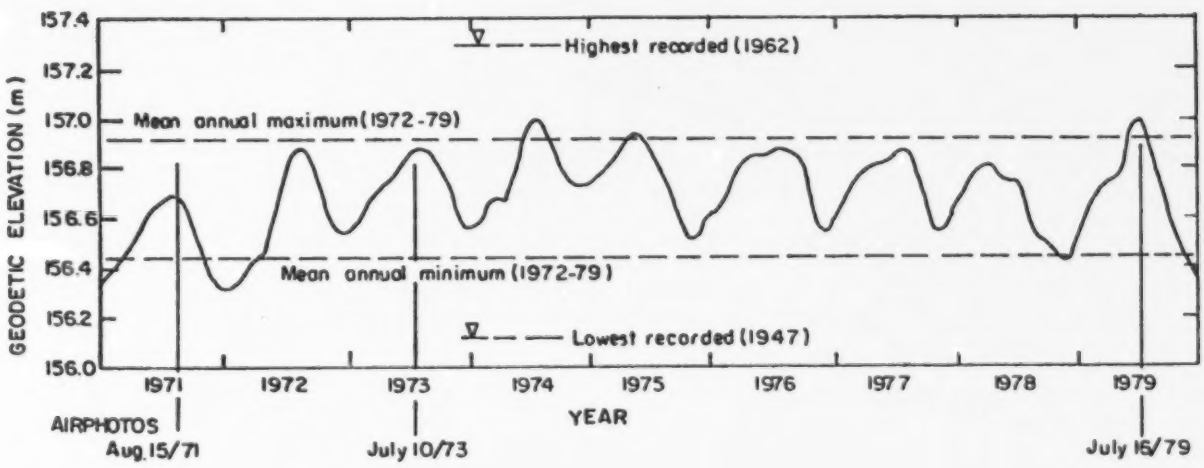
FIGURE 17b



Retreat of the Wisconsin ice margin in vicinity of the Slave River delta. Inferred position of retreating ice margin is given in thousands of radiocarbon years BP (before present). After Map 1257A by V.K. Prest, Geological Survey of Canada 1969. Scale: 1:5,000,000.

FIGURE 19

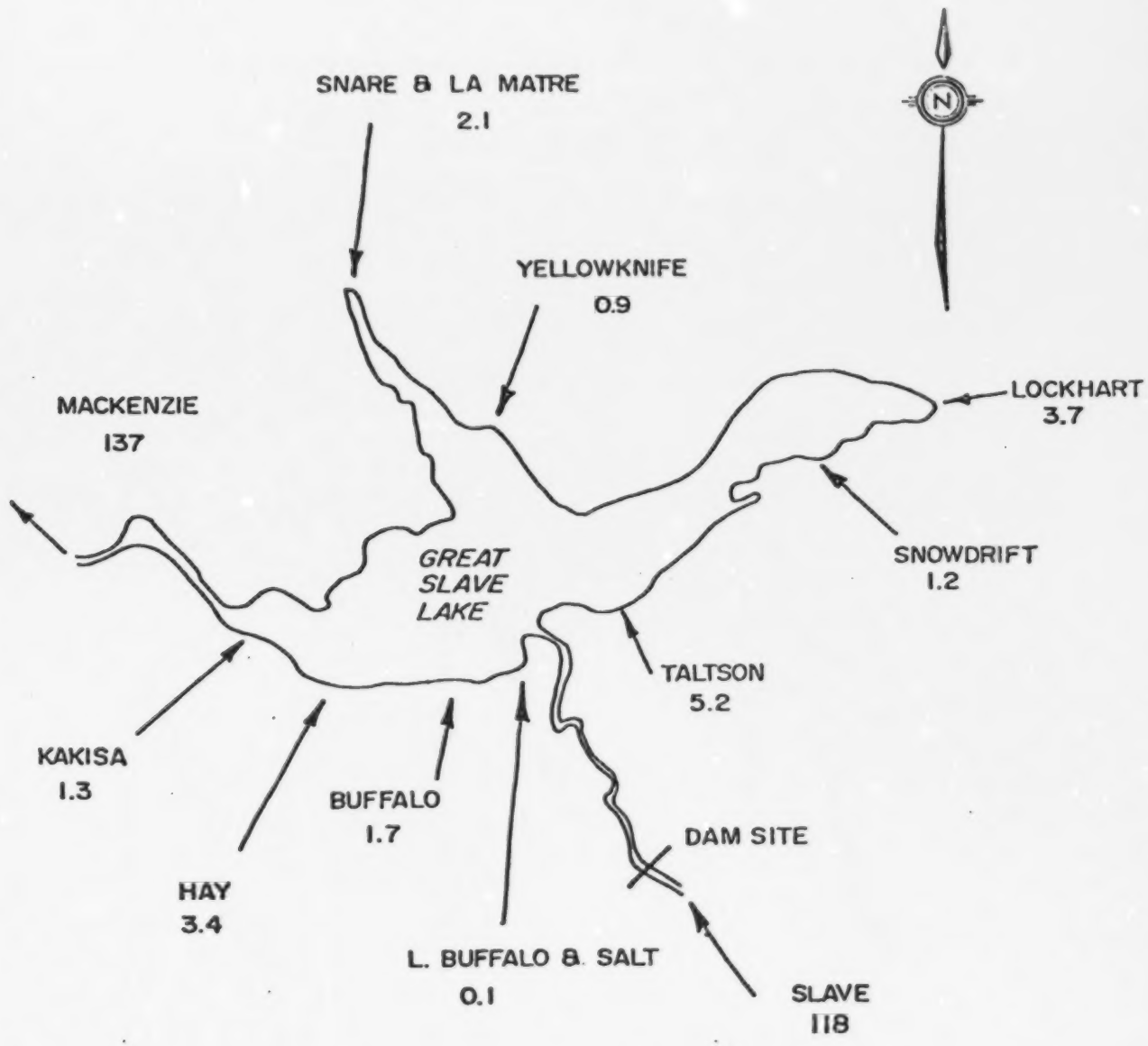
1968–72 affected by filling of Williston Reservoir on Peace River



NOTE: Based on Water Survey of Canada records for Great Slave Lake at Yellowknife Bay

MONTHLY WATER LEVELS IN GREAT SLAVE LAKE, 1971 – 79

FIGURE 20

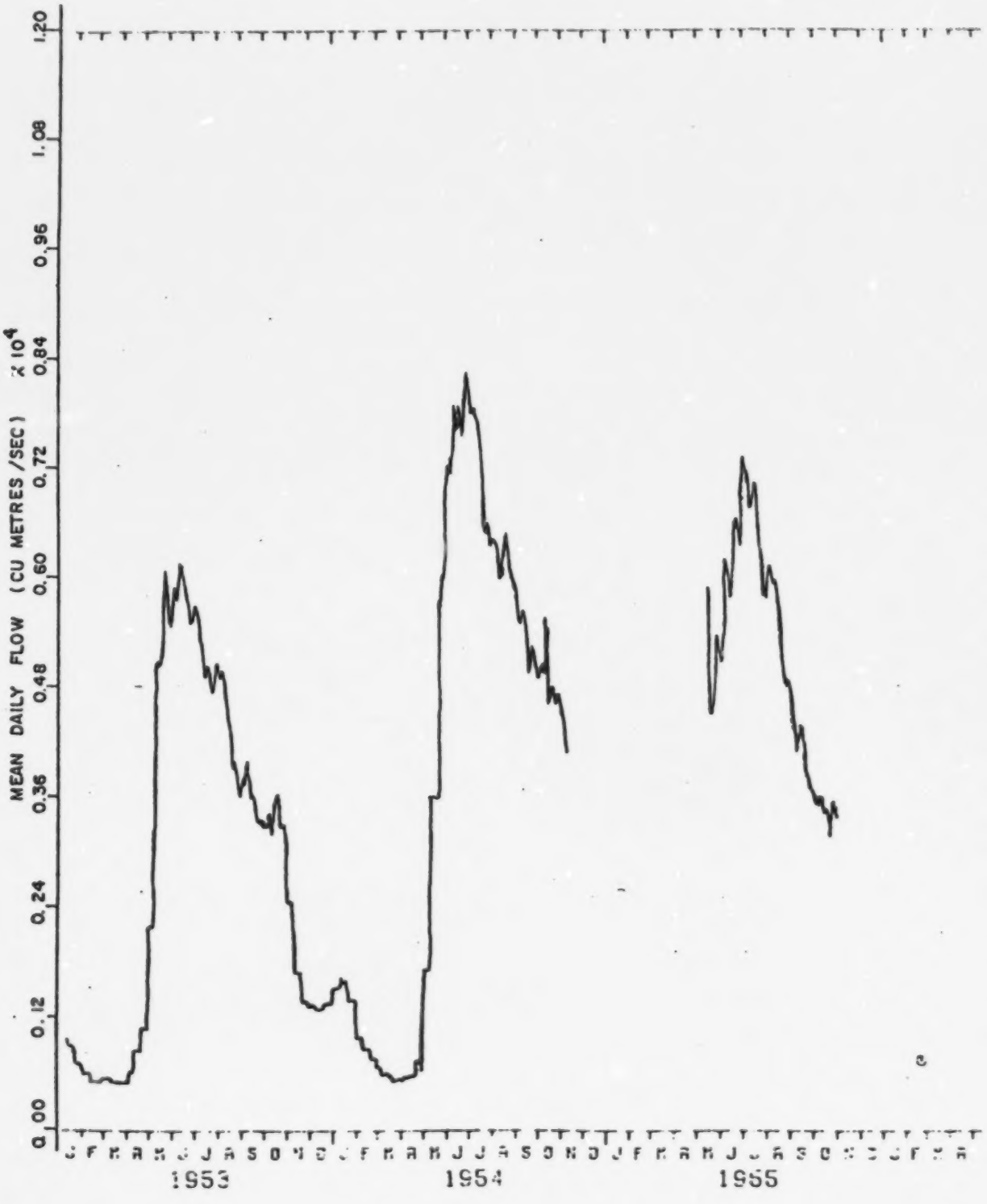


NOTE: UNITS ARE IN km^3/year

MEAN WATER BALANCE FOR GREAT SLAVE LAKE

FIGURE 21

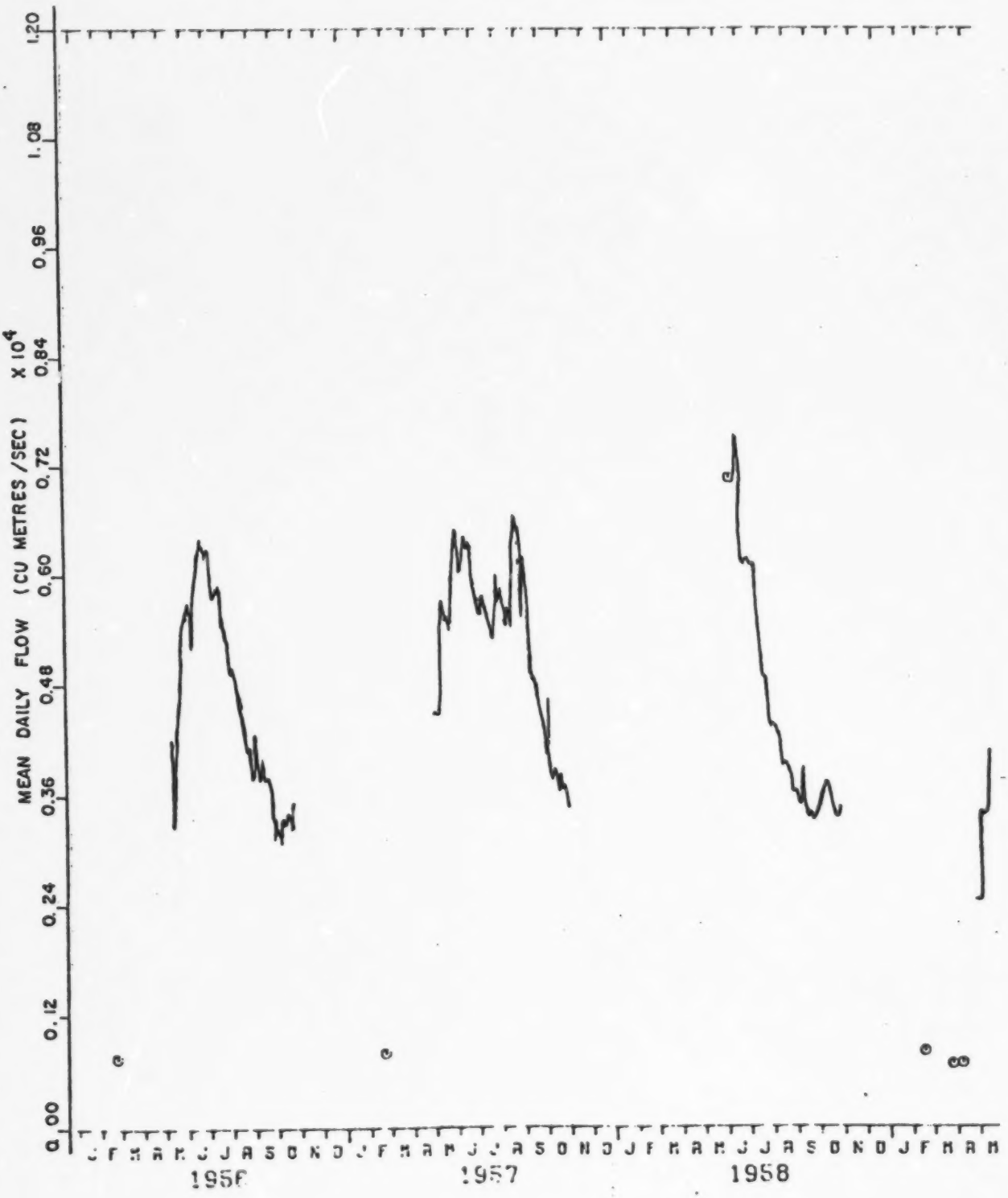
NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

FIGURE 22

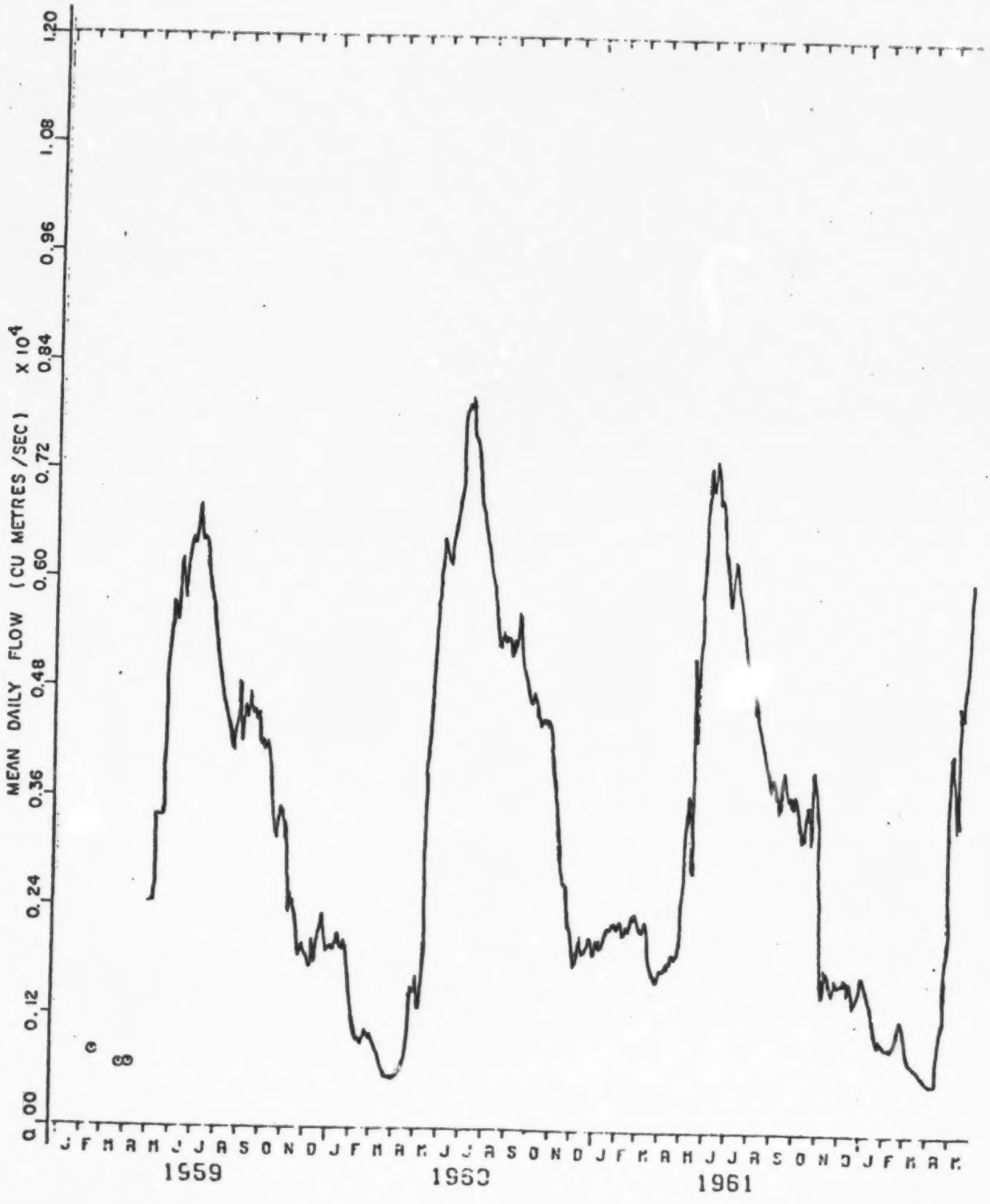
NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

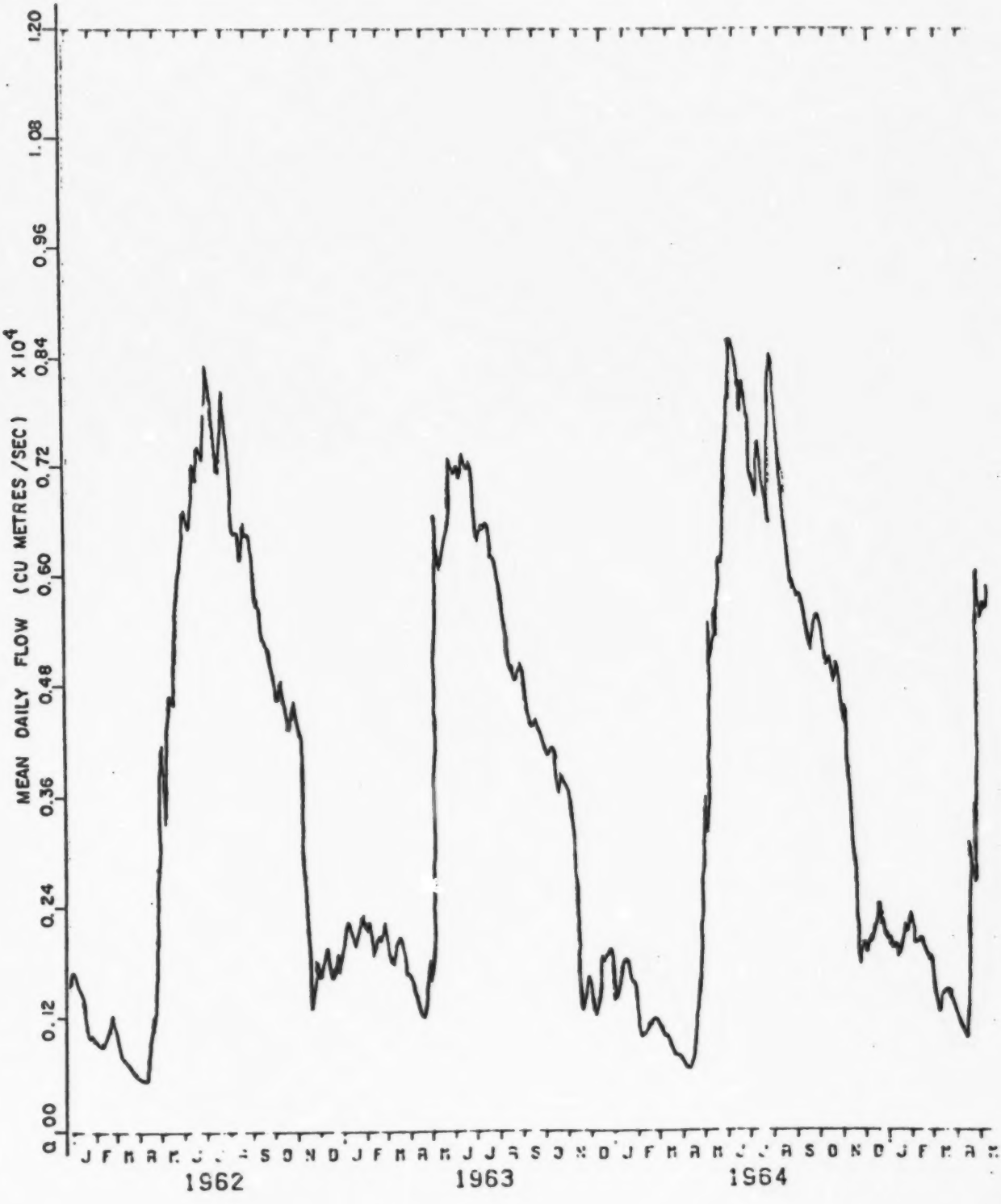
FIGURE 22

NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

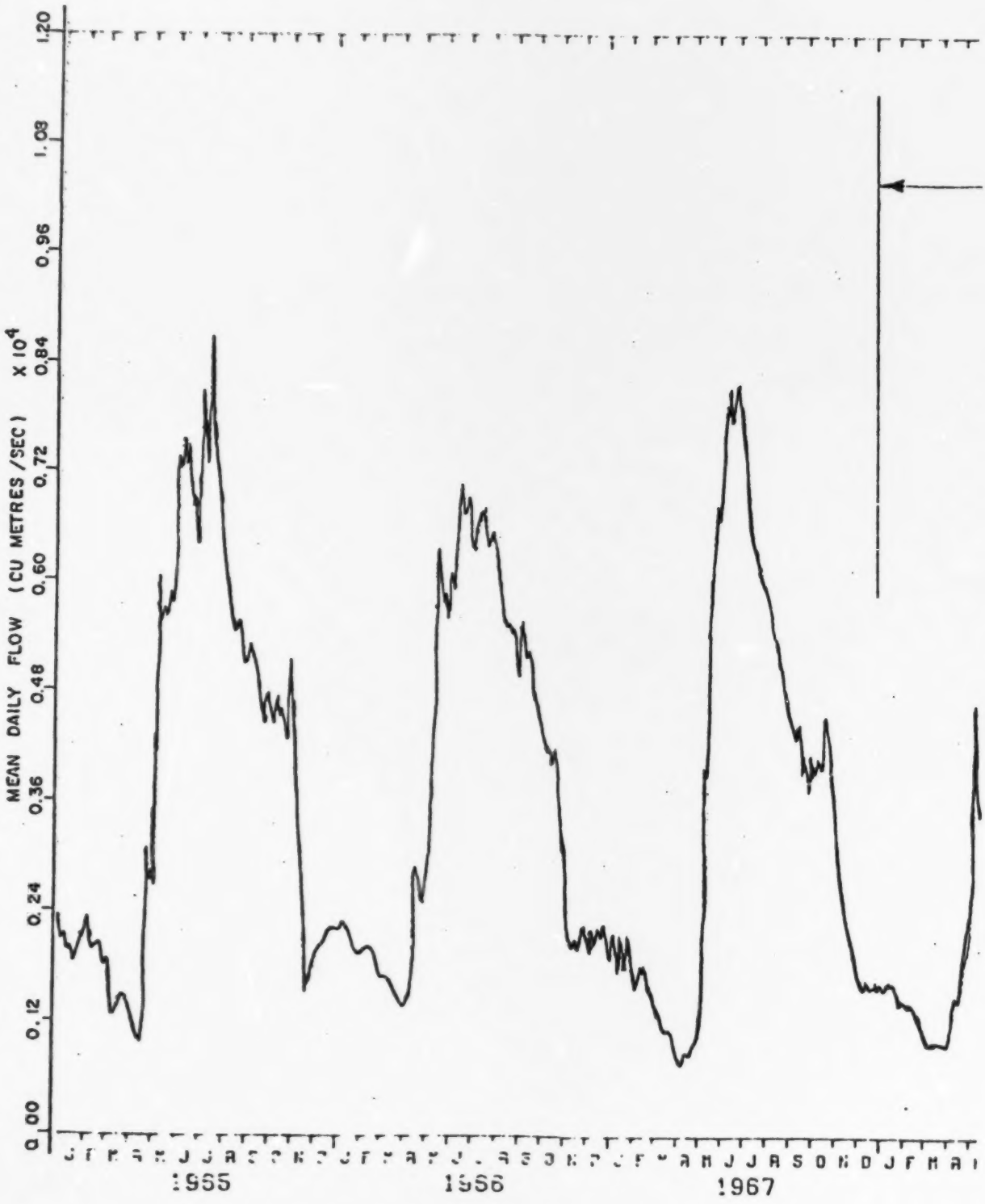
NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

FIGURE 22

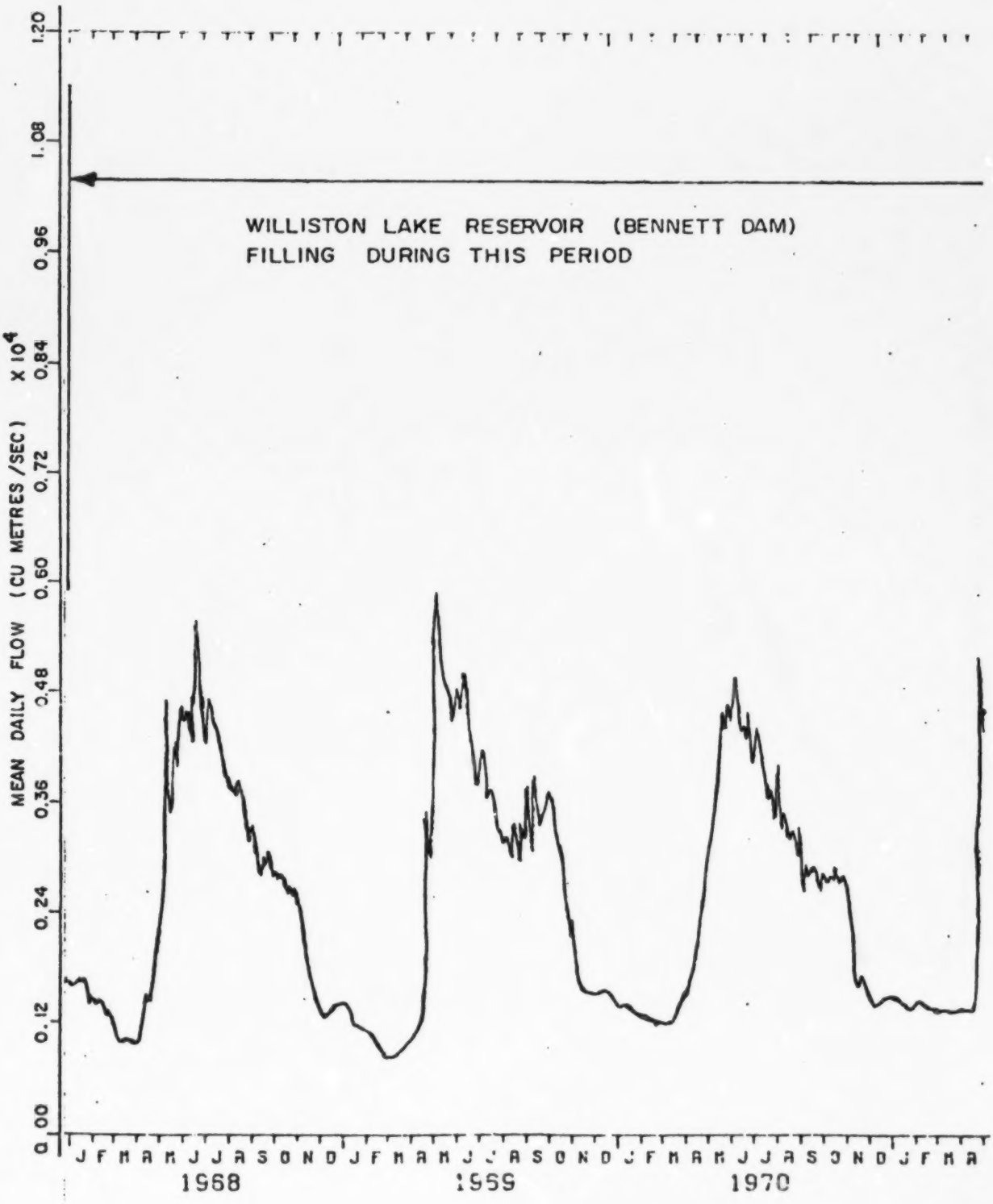
NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

FIGURE 22

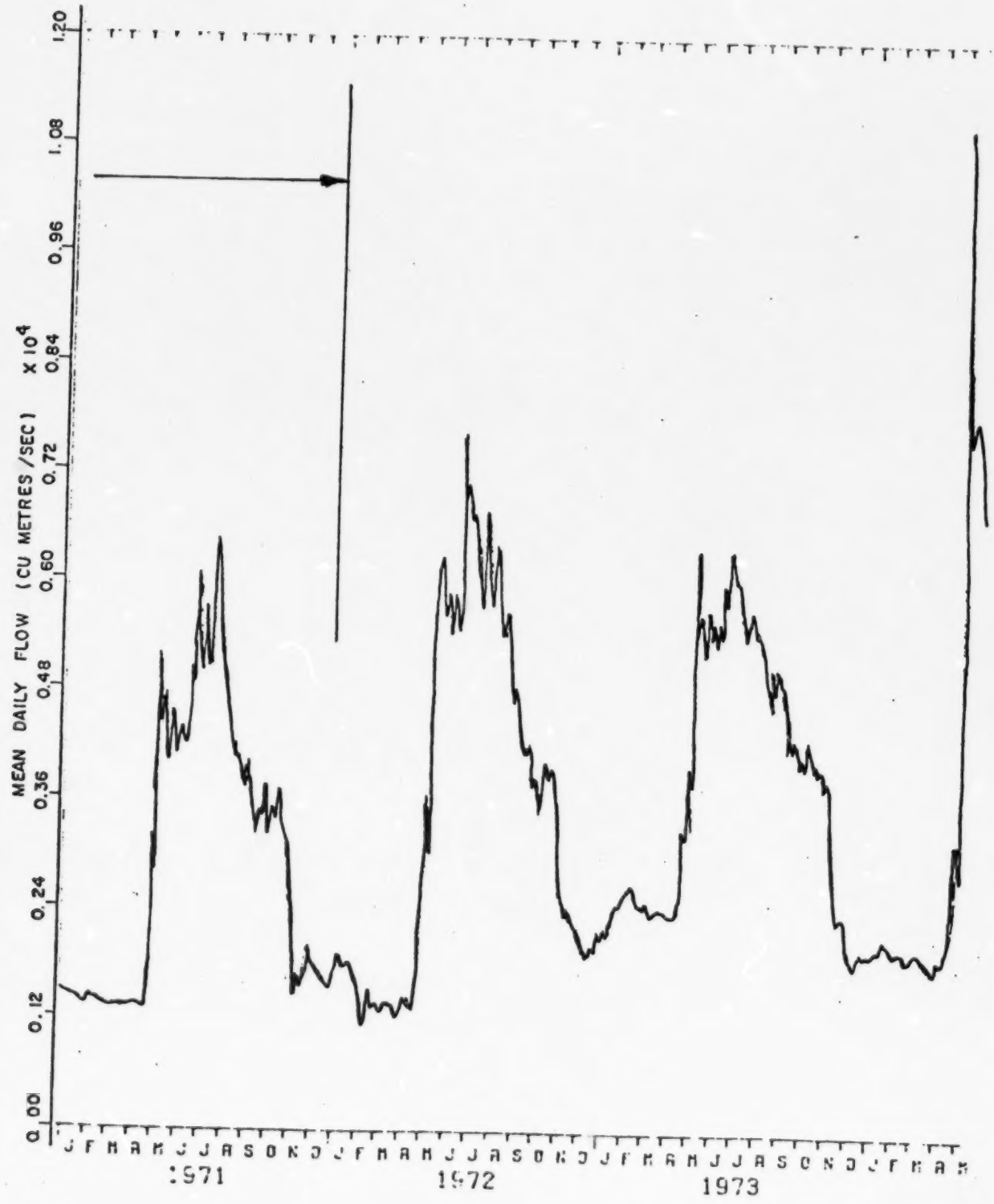
NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

FIGURE 22

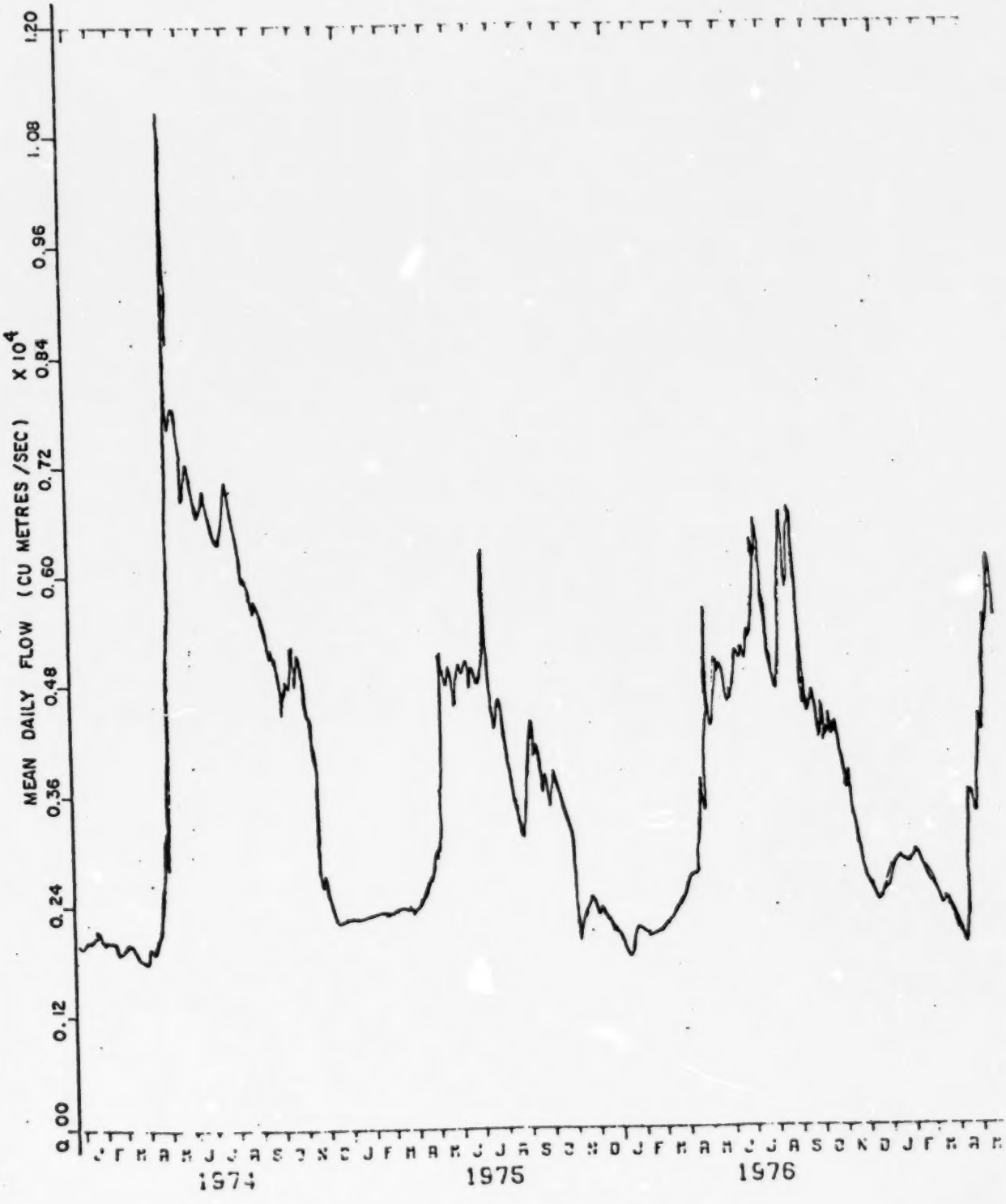
NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

FIGURE 22

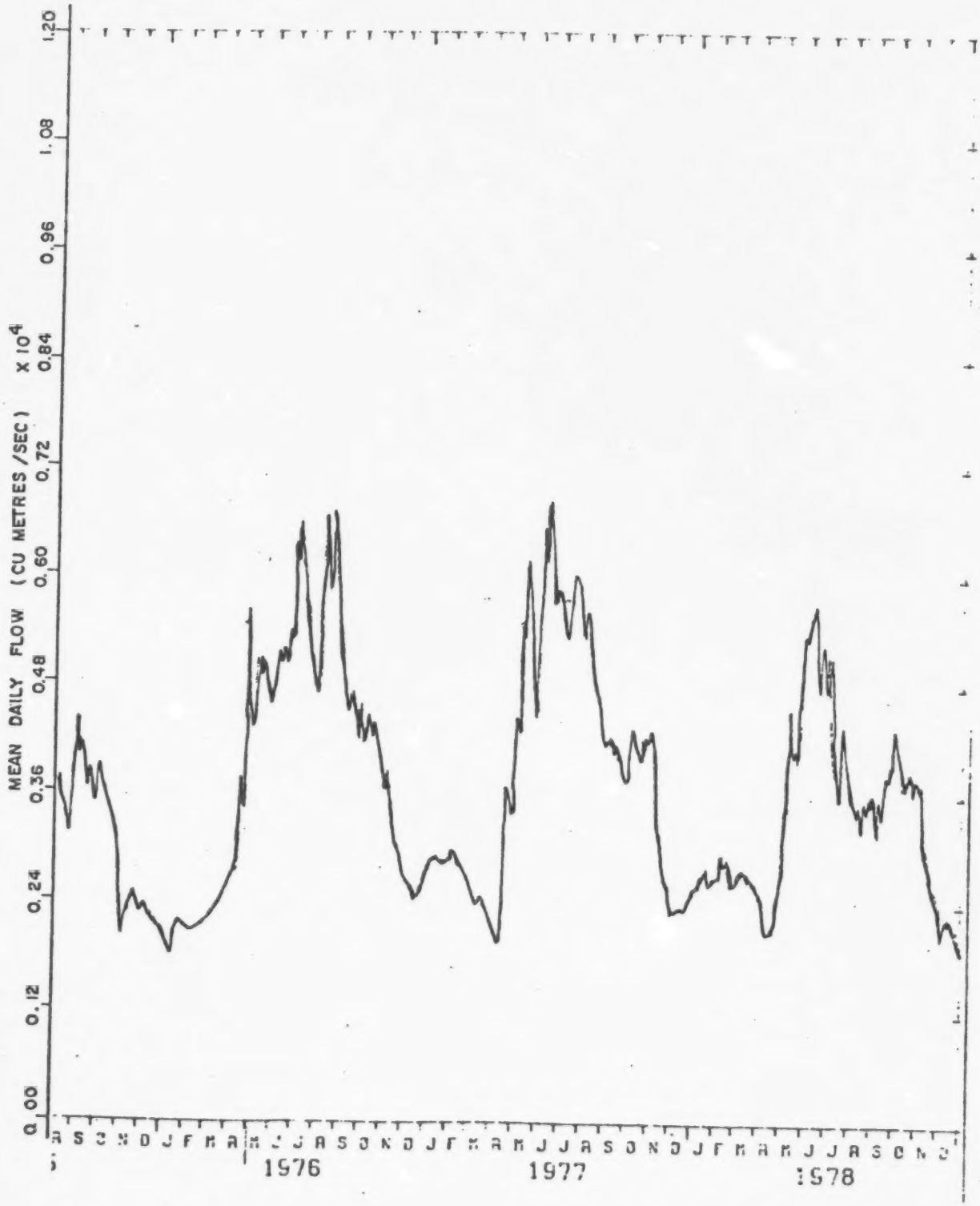
NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

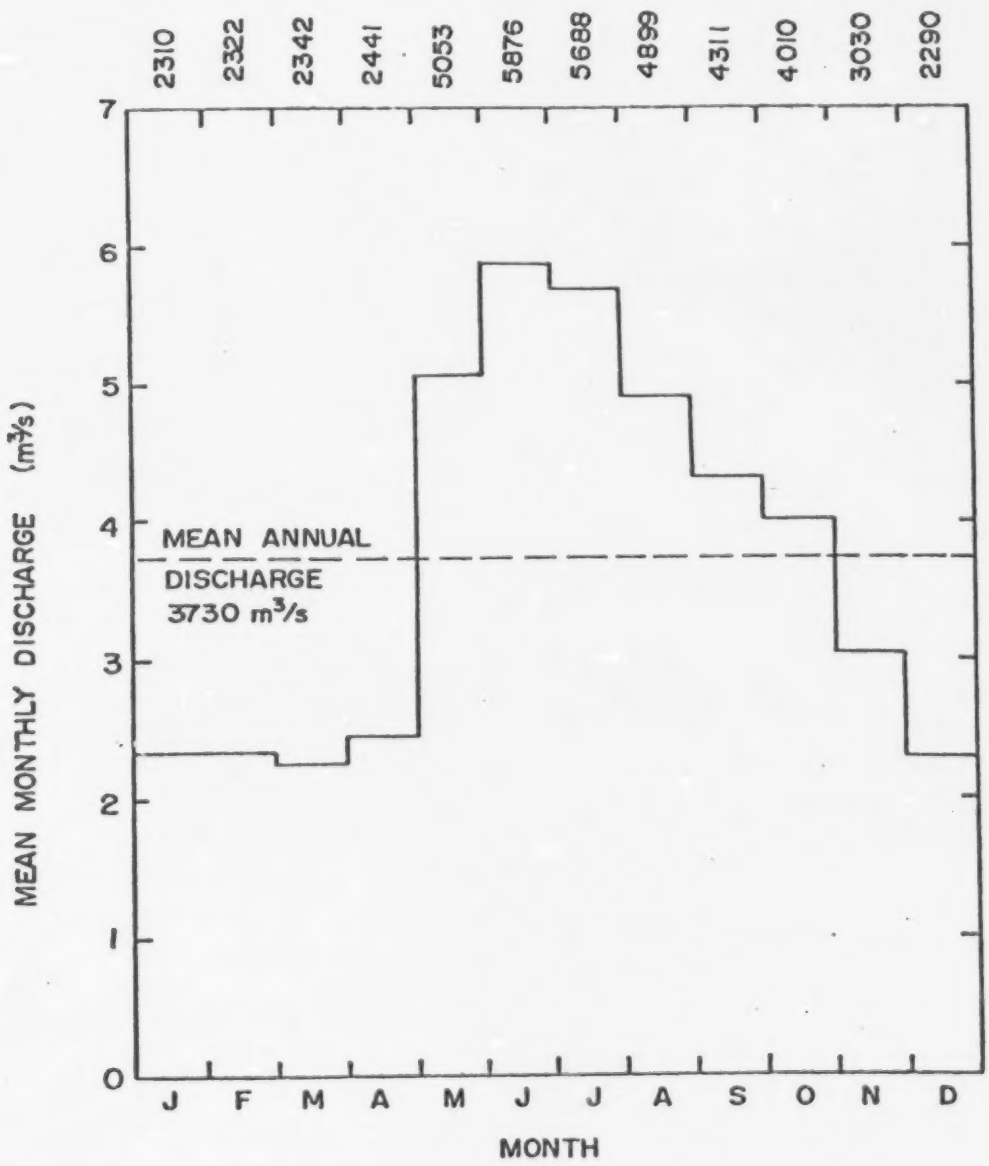
FIGURE 22

NOTE: DATA RECORDED BY WATER SURVEY OF CANADA, GAUGING STATION 07NB001, SLAVE RIVER AT FITZGERALD



SLAVE RIVER DISCHARGE HYDROGRAPH, 1953-78

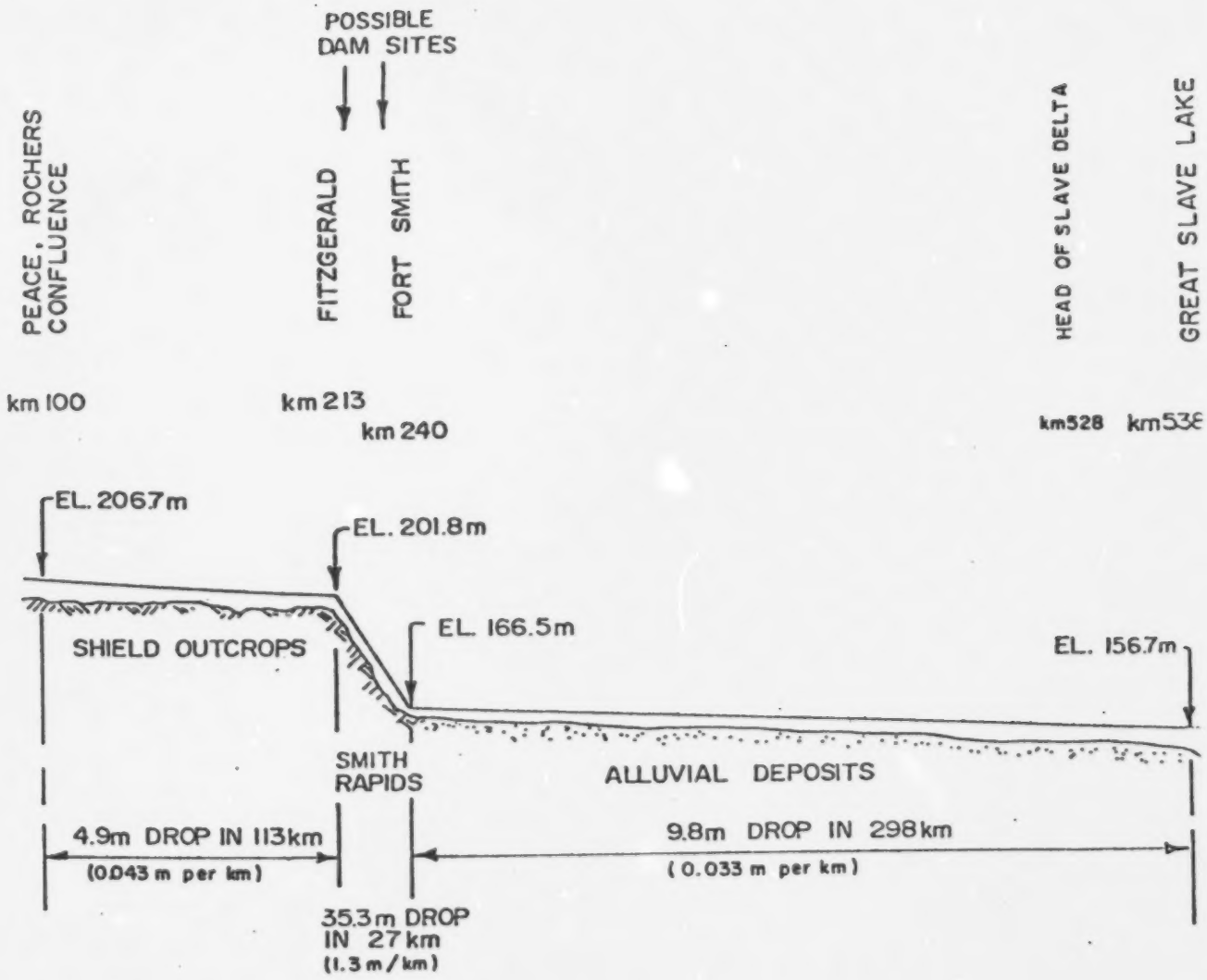
FIGURE 22



NOTE: MEAN MONTHLY VALUES BASED ON WATER SURVEY OF CANADA RECORDS FOR THE SLAVE RIVER AT FITZGERALD (07NB001) 1972-79, MEAN ANNUAL VALUE BASED ON RECORDS 1960-67 AND 1972-79

MEAN SLAVE RIVER FLOW DISTRIBUTION BY MONTHS FOR POST – BENNETT DAM PERIOD, 1972-79

FIGURE 23



NOTE: WATER SURFACE ELEVATIONS OF RIVER APPROXIMATELY CORRESPOND TO THE MEAN ANNUAL DISCHARGE OF 3730 m^3/s, WHILE THE SURFACE ELEVATION OF THE LAKE IS THE MEAN LAKE LEVEL.

LONGITUDINAL PROFILE OF THE SLAVE RIVER

FIGURE 25

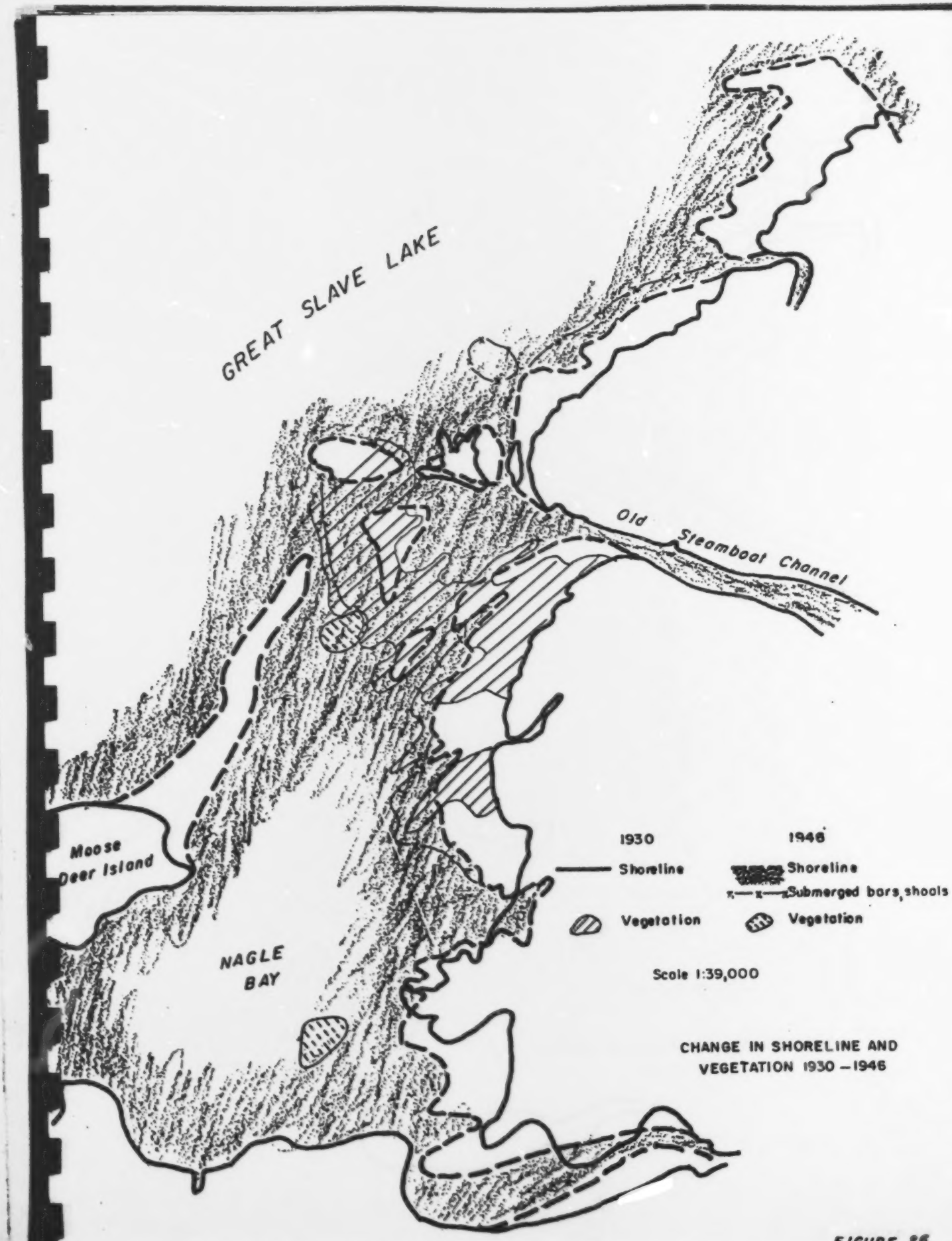

GREAT SLAVE LAKE
Old Steamboot Channel
Moose Deer Island
NAGLE BAY
1930
Shoreline
Vegetation
1948
Shoreline
Submerged bars, shoals
Vegetation
Scale 1:39,000
CHANGE IN SHORELINE AND VEGETATION 1930 – 1948

FIGURE 26

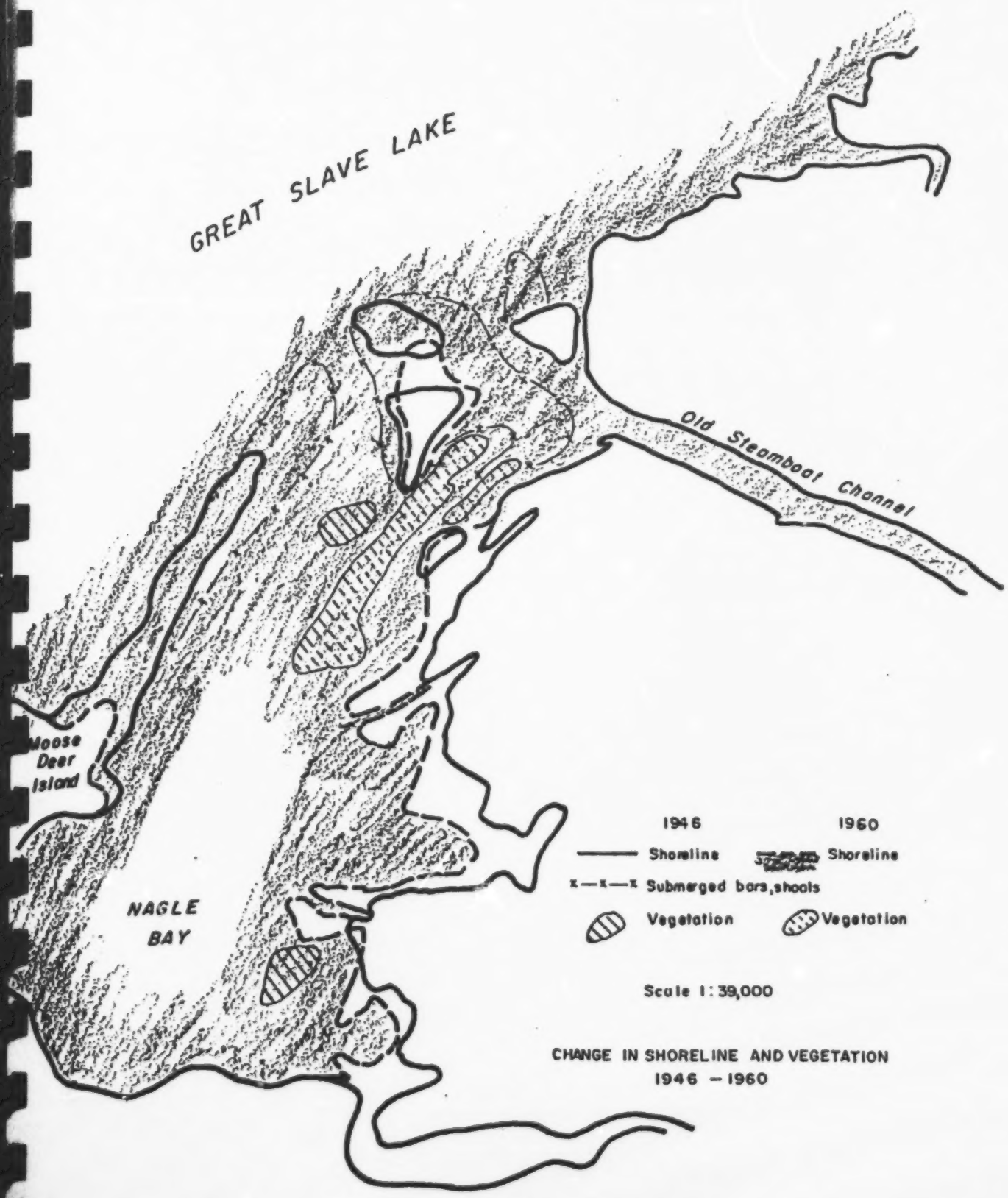
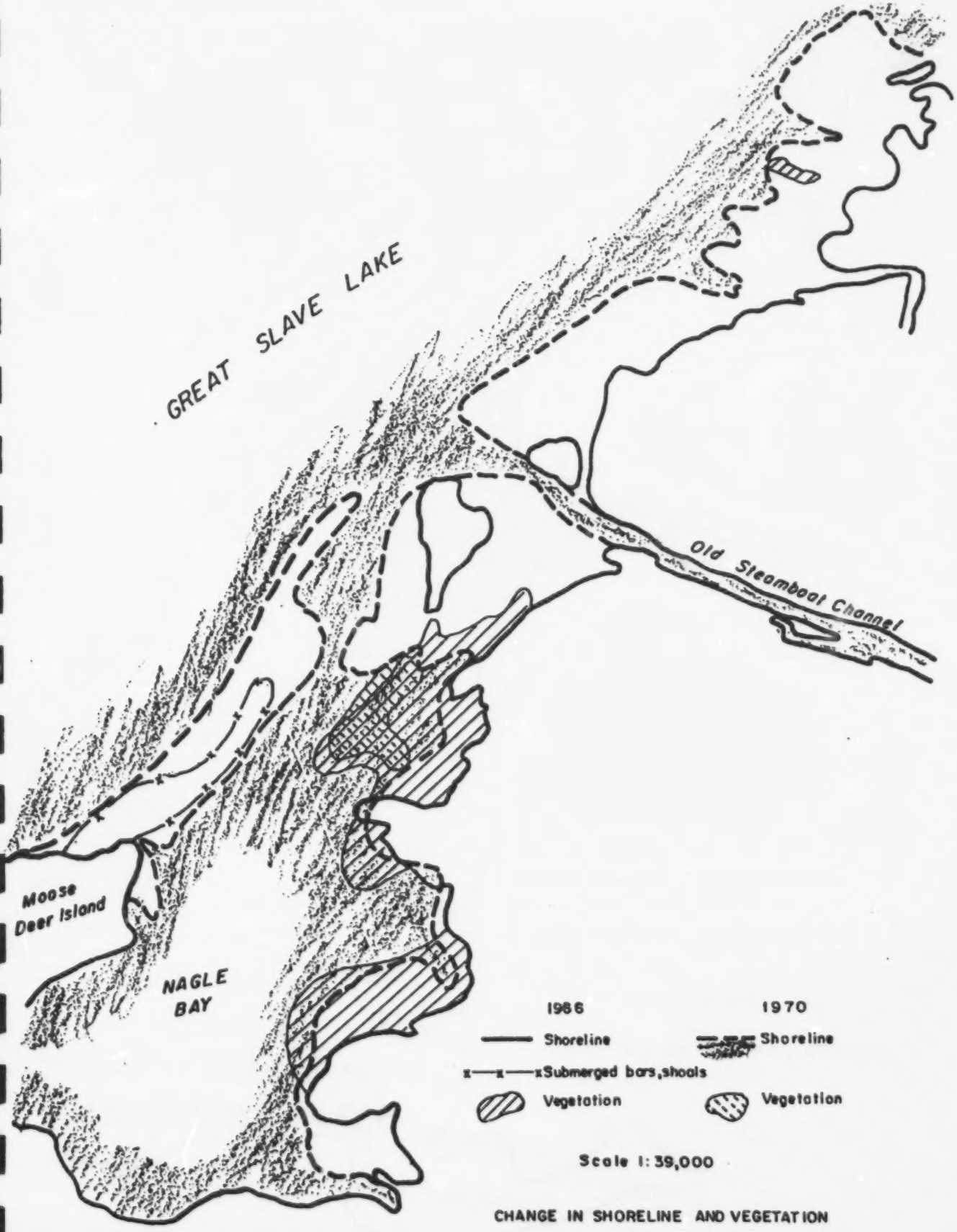

GREAT SLAVE LAKE
Old Steamboat Channel
Moose Deer Island
NAGLE BAY
1946
1960
Shoreline
Shoreline
Submerged bars, shoals
Vegetation
Vegetation
Scale 1:39,000
CHANGE IN SHORELINE AND VEGETATION
1946 – 1960

FIGURE 27



CHANGE IN SHORELINE AND VEGETATION
1966 – 1970

FIGURE 28

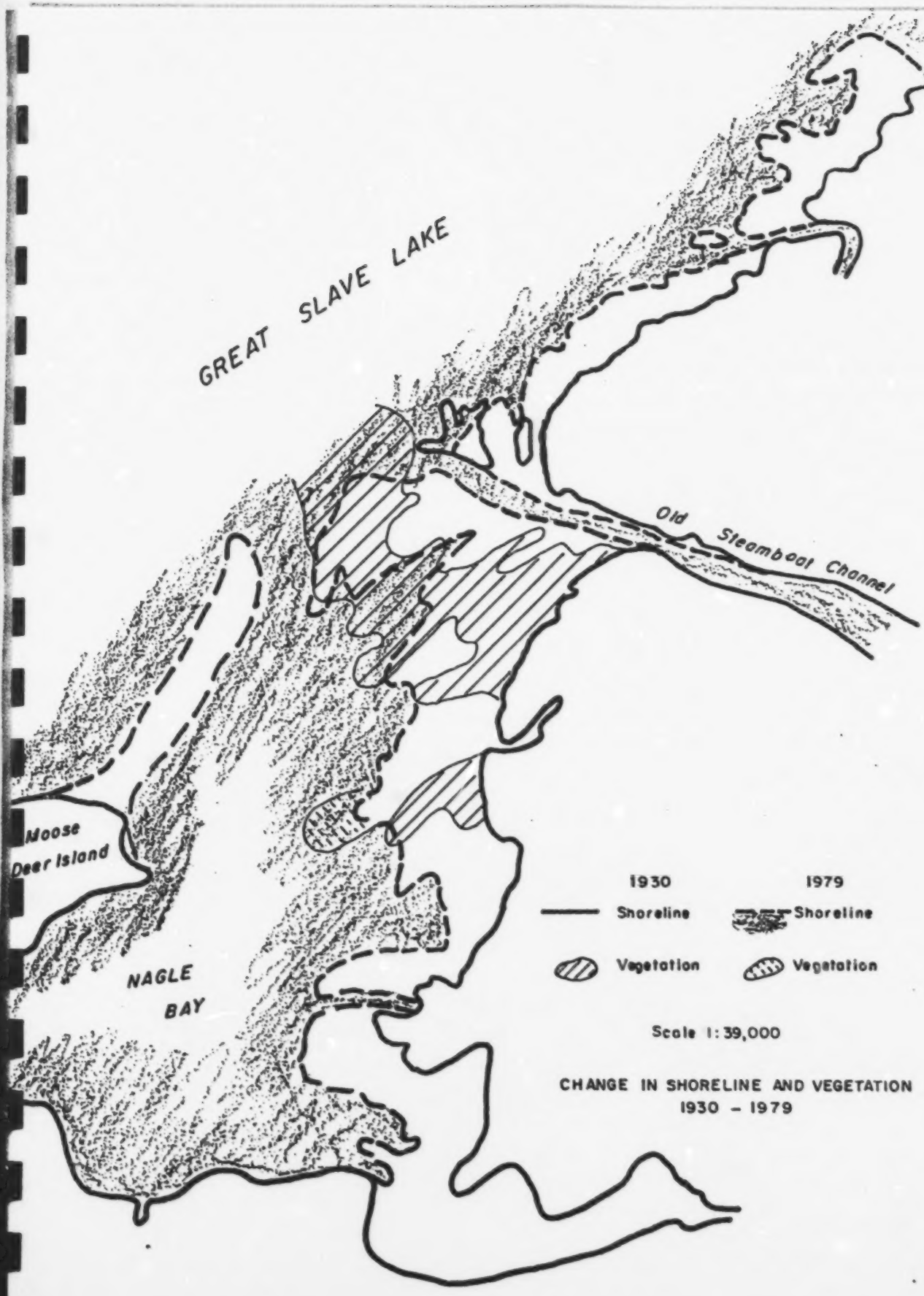
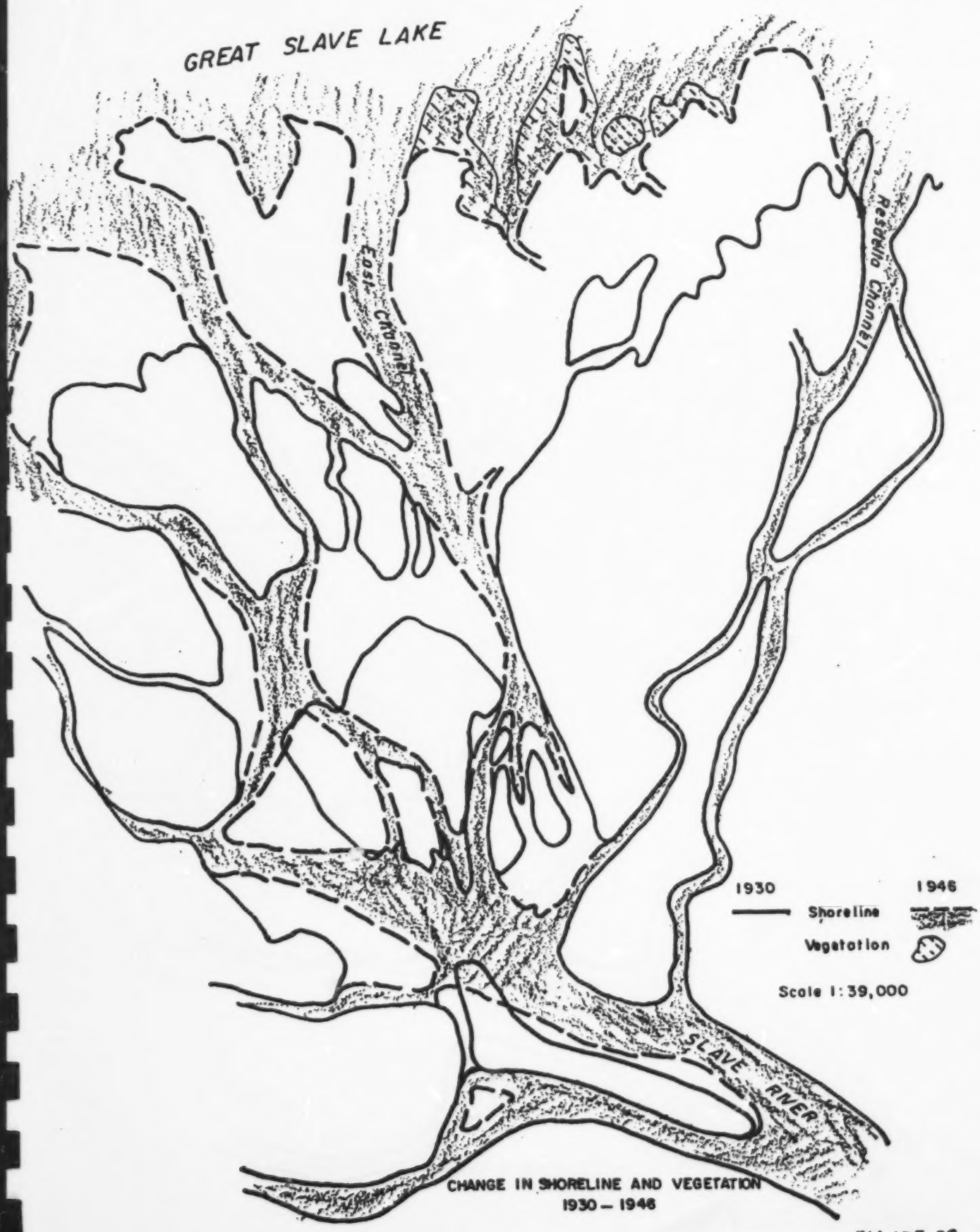
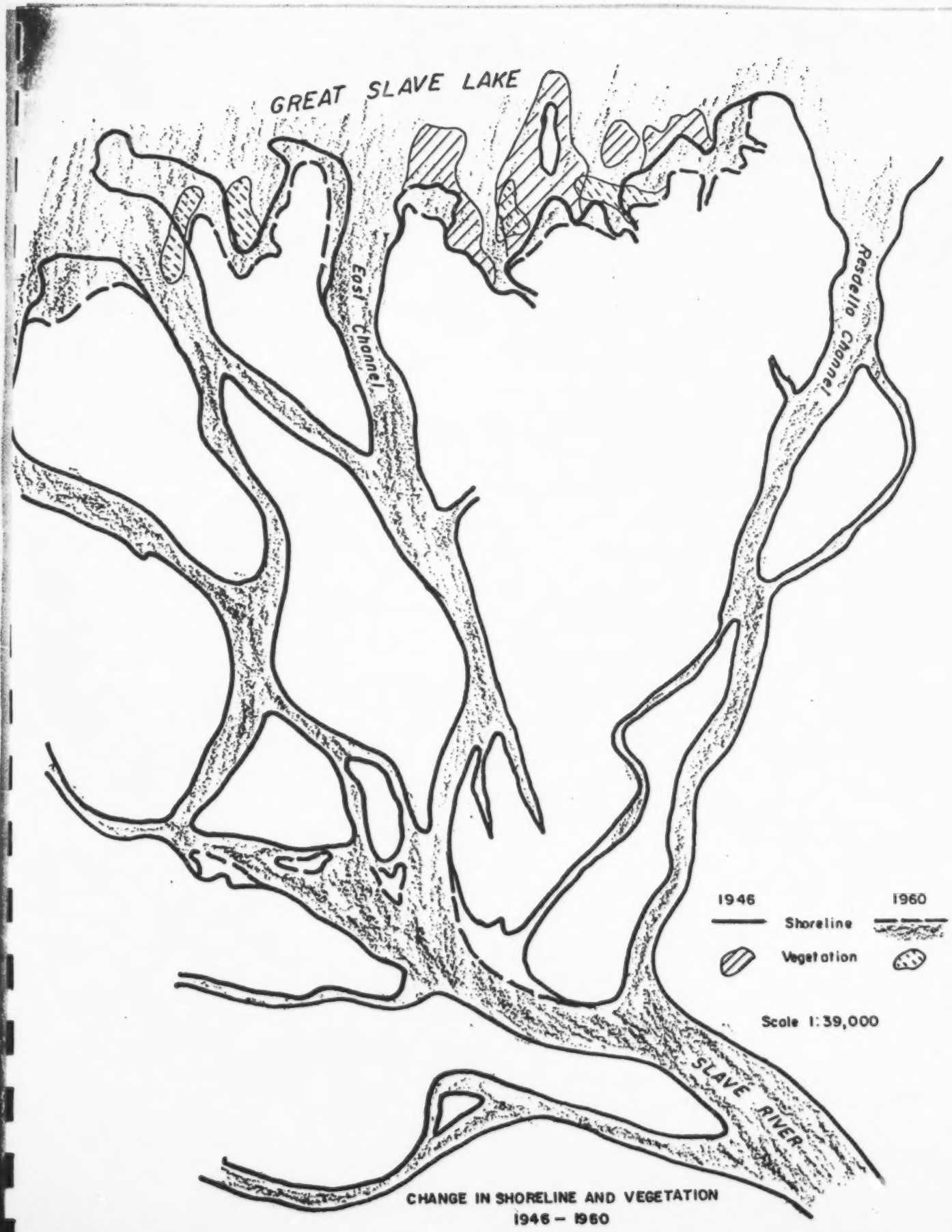

GREAT SLAVE LAKE
Old Steamboat Channel
Moose
Deer Island
NAGLE
BAY
1930
1979
Shoreline
Shoreline
Vegetation
Vegetation
Scale 1:39,000
CHANGE IN SHORELINE AND VEGETATION
1930 - 1979

FIGURE 29



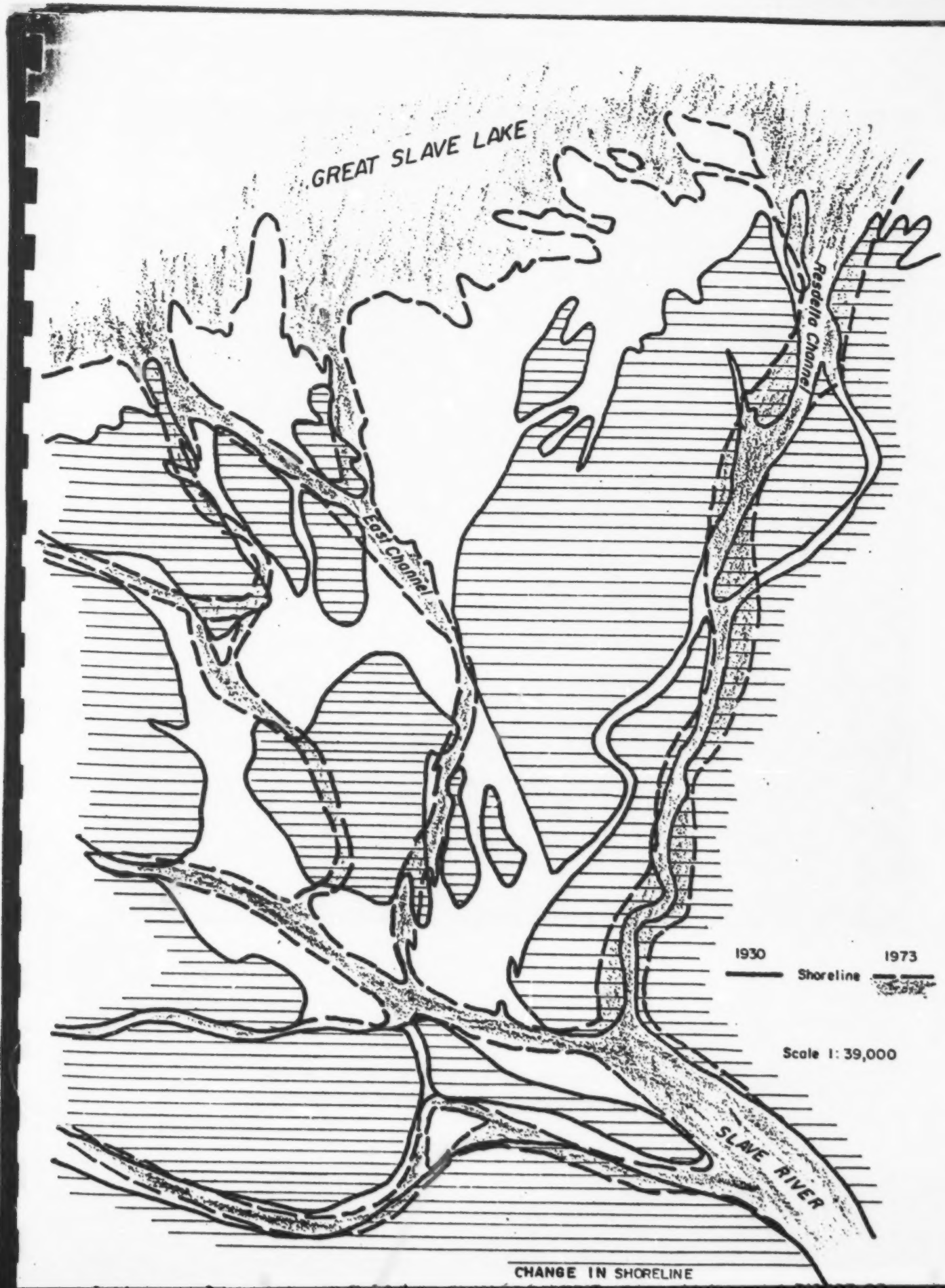
CHANGE IN SHORELINE AND VEGETATION
1930 – 1946

FIGURE 30



CHANGE IN SHORELINE AND VEGETATION
1946 – 1960

FIGURE 31

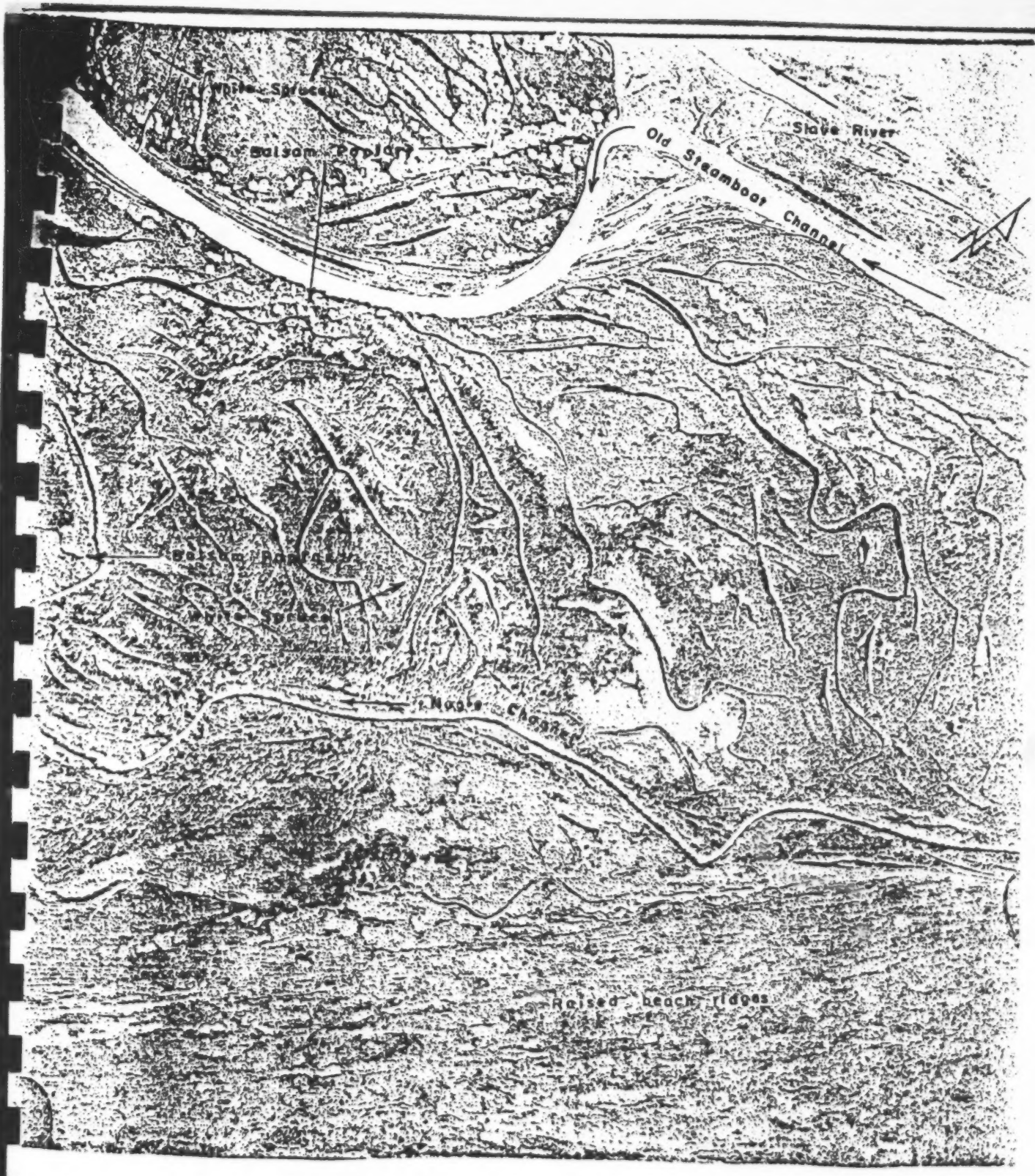


CHANGE IN SHORELINE

ACTIVE DELTA DEPOSITION AND NEARSHORE VEGETATION (PROBABLY HARDSTEM BULRUSH (SCIRPUS ACUTUS). SEPTEMBER, 1966

Scale 1:24,000

FIGURE 38



BALSAM POPLAR AND WHITE SPRUCE ALONG NAGLE CHANNEL, SLAVE RIVER DELTA, SEPTEMBER, 1966

Scale 1:24,000

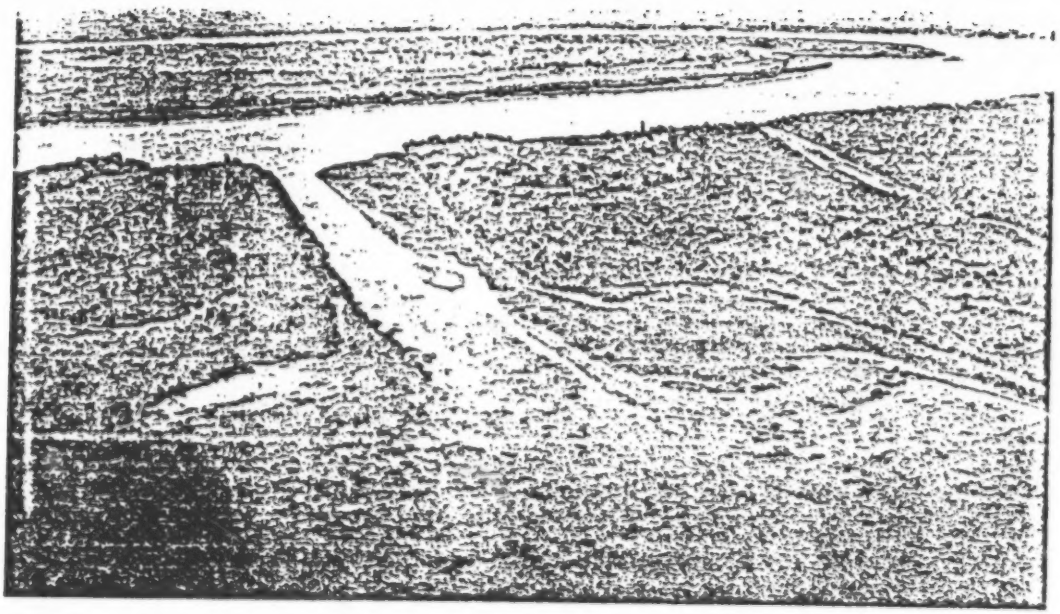


Photo Km 497. Outlet of Ring Lake, an ancient meander loop of the Slave River. The outlet channel of the lake is shallow and water from the Slave is not entering the lake. (24 July 1980) 403-18-29.

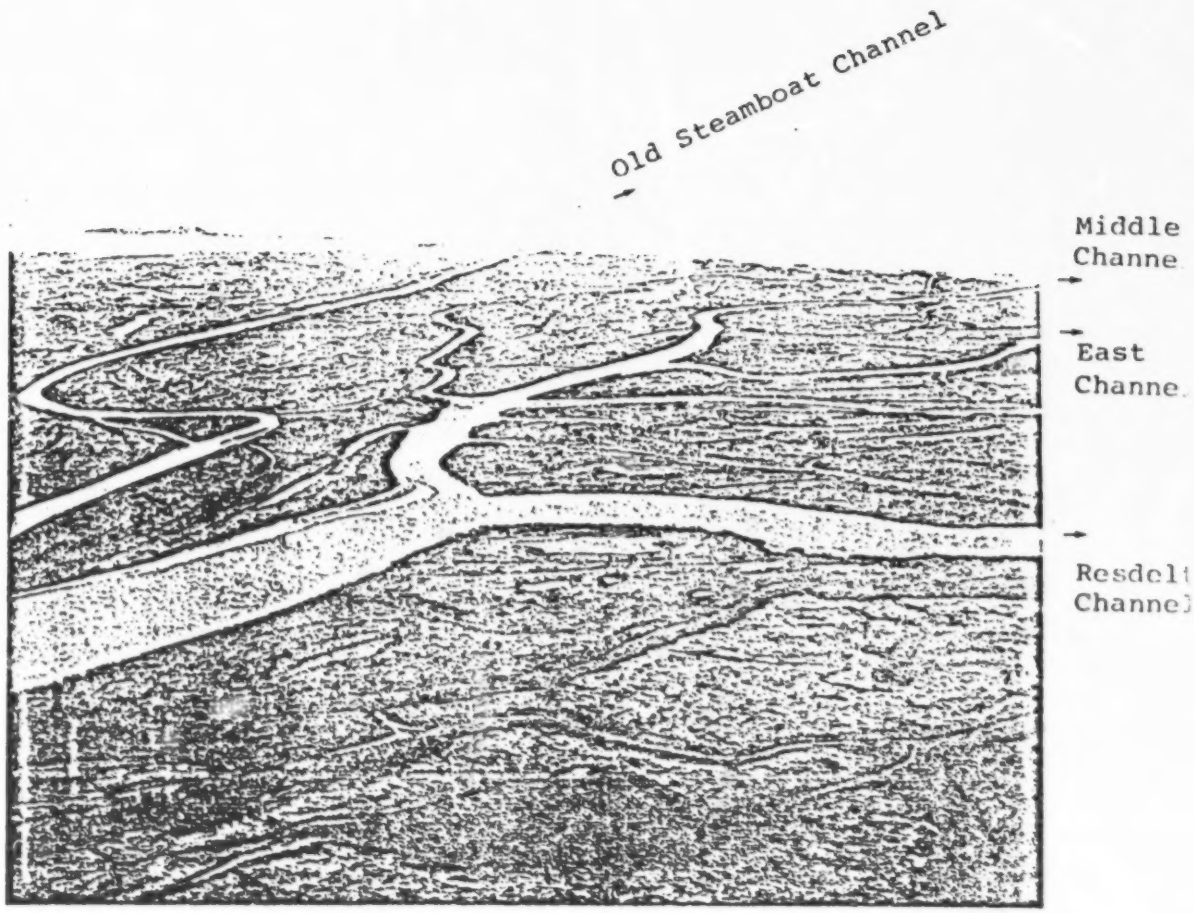


Photo Km 528. Head of the Slave Delta with Great Slave Lake in the background. The bar at the entrance to the Middle and East Channels probably signifies that these channels are losing flow to the Resdelta Channel which presently conveys most of the flow.
(24 July 1980) 403-19-9.

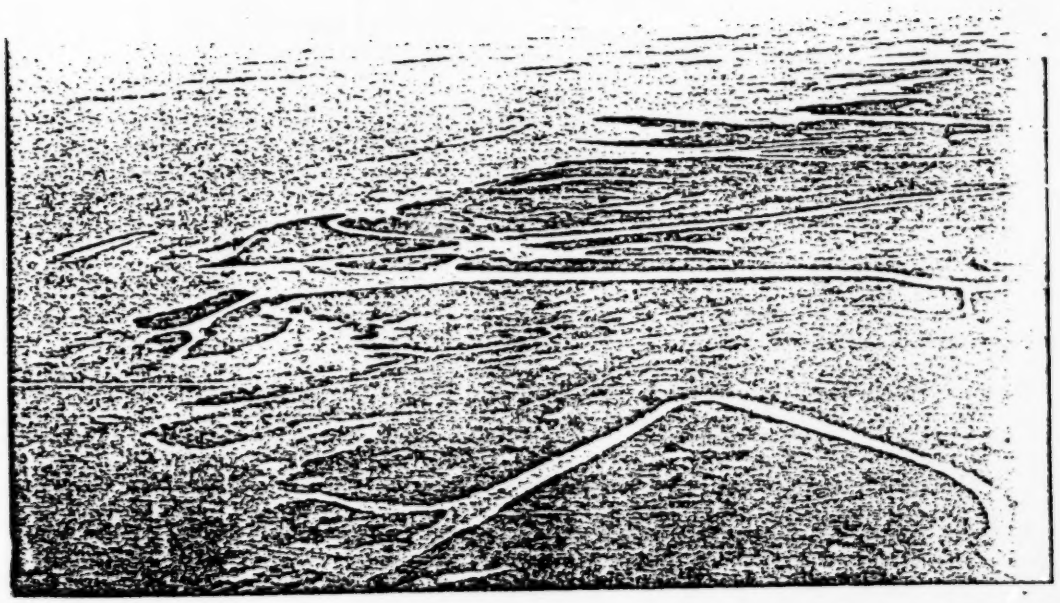


Photo Km 538. Slave Delta from the south where it enters the lake. Note the bars in the lake which mark the limit of the delta. These bars are probably formed from Slave River sediments that have been halted by littoral action. (24 July 1980) 403-19-5.